

Final Report

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**ECONOMIC IMPACT OF AIR POLLUTANTS
ON PLANTS IN THE UNITED STATES**

Prepared for:

COORDINATING RESEARCH COUNCIL
NEW YORK, NEW YORK

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I INTRODUCTION

Public concern, complaints of the agricultural industry, and the continuing increase in the number of claimed losses have made it important to determine the value of losses to crops and ornamentals caused by air pollutants. This includes identifying the losses caused by each major pollutant and the geographical areas in which the losses are occurring.

Some gross estimates have been made of economic losses due to air pollutants but, for the most part, these have been total estimates, and no attempt has been made to distribute the aggregate loss among farm crops, forests, ornamental plantings and home gardens, by pollutant or by geographical region. Thus the proportions of loss that can be ascribed to emissions from manufacturing operations, smelting processes, automobile exhausts, and other sources are not known.

The Coordination Research Council, a nonprofit organization, entered into a contract with Stanford Research Institute to develop gross estimates of economic losses resulting from the effects of air pollutants on plants. Monitoring the program is the Coordinating Research Council's Air Pollution Research Advisory Committee (APRAC), a group of technical experts from industry and government. Program funding was made available by the Automotive Manufacturers Association, the American Petroleum Institute and the Environmental Protection Agency. This report describes the results of the second year's effort.

The objectives of the first year's study were to provide background information believed helpful and essential to the problem and, based on this information, to estimate the dollar loss resulting from the effect of pollutants on plants. As a result of discussions among members of a Steering Committee consisting of SRI staff and CRC-APRAC personnel, plans of work were evolved that were generally followed during the course of the study. The work plan consisted of the following:

1. Review of methods used by other agencies to estimate crop losses caused by factors other than air pollutants, such as plant diseases, insect pests, and adverse weather conditions.
2. Continuing literature review concerning the relative sensitivity of some 65 different crop and ornamental plants to various air pollutants.

3. Listing of potential sources of industrial and domestic plant-damaging air pollutants by county, and estimating the severity of the pollution for each county.
4. Calculation of the economic value of the individual crops in these counties.
5. Derivation of formulae for evaluating the dollar loss to plants as a result of air pollution effects.
6. Estimation of dollar loss to agricultural crops for each county by use of the formulae and background data obtained.

During the first year's study, the above work plan was followed and first-estimate values were obtained on the occurrence by county of air pollution conditions, dollar value and production of crops in these counties, and the sensitivity of some 65 major crops to air pollutants. The following formula was developed for estimating the approximate dollar loss of a particular crop due to a particular pollutant.

$$C = P^P Q^P \left(\frac{Q^C - Q^P}{Q^C} \right)$$

where C = approximate dollar loss

P^P = price per unit produced under polluted conditions

Q^P = number of units produced under polluted conditions

Q^C = potential units produced under clean conditions.

Essentially, this states that dollar loss is equal to the value of the crop times the percentage reduction in yield ascribable to the pollutant.

Application of this formula to the sensitive crops in the counties where pollution occurred resulted in the following estimates of loss to commercial crops only:

\$65,000,000 due to oxidants (ozone, PAN, and nitrogen oxides)

3,500,000 due to sulfur dioxide

3,000,000 due to fluorides.

These estimates did not include losses to ornamentals and home plantings.

It was recognized that these were first estimates and that improvements and additions should be made. Some of the more important deficiencies in the first report were as follows:

1. Estimates of severity of pollution in various counties were based on emission data only, and the effects of meteorological and other factors in concentrating or diluting these emissions were not given proper consideration.
2. In estimating the loss of individual crops, it was assumed that crops considered sensitive to a given pollutant were equally sensitive and those resistant were equally resistant.
3. The omission of the losses to ornamental planting was not overlooked, but time did not permit the acquisition of the necessary information.

The second year's study was aimed primarily at revising the estimates to correct the deficiencies described in Items 1 and 2 above and to include estimates of loss to ornamental plants.

This report describes the studies conducted from September 1, 1970, to August 31, 1971, and presents revised estimates of dollar losses due to oxidants, sulfur dioxide, and fluorides in the United States.

II SUMMARY

Following the outline of work described in the Introduction, the activities and results may be summarized as follows.

1. Counties in the United States where the major air pollutants--oxidants (ozone, PAN, and oxides of nitrogen), sulfur dioxide, and fluorides--were likely to reach plant-damaging concentrations were selected. The selections were made on the assumption that such concentrations of oxidants and sulfur dioxide were likely to occur in the most populous counties, i.e., those in the Standard Metropolitan Statistical Areas (SMSAs), where fuel consumption was the greatest and hence the emissions of these compounds or their precursors to the atmosphere would also be the greatest, and in counties containing large single-source emitters of sulfur dioxide (such as power plants and copper smelters) or of fluorides (such as aluminum, phosphate and ceramic plants).

2. The relative potential severity of the pollution in each county was then estimated. The severity of the oxidant pollution was derived by first estimating, from fuel consumption data, the tons of hydrocarbons and oxides of nitrogen (the precursors of oxidants) emitted per square kilometer per day. These emissions values were then multiplied by a factor related to area of the county or SMSA and by a concentration rate factor (designated $\bar{x}/q$). The product of these multiplications yielded a value indicative of the relative concentration of oxidant that might be reached in a single pollution episode. These values were again multiplied by the number of days involved in pollution episodes over a five-year period, which yielded a value indicative of the overall plant-damaging potential for oxidant pollution in the various counties.

The same procedure was followed for estimating the plant-damaging potential for sulfur dioxide pollution in the various counties, but the effect of large single-source emitters in the counties was also taken into consideration.

For fluorides, the relative plant-damaging potential was based on the number, type and size of large single-source emitters present.

After arranging the counties in order of severity of potential plant-damaging pollution, they were then grouped into classes of varying severity. For oxidants, seven classes were developed, ranging from those counties where the pollution potential was greatest to those where no pollution potential seemed to exist. Those counties with sulfur dioxide plant-damaging potential were split into six classes and those with fluoride potential, into four classes.

3. The dollar value of grass hay produced and of pastures (as hay equivalent) in the potentially polluted counties was calculated. With these results, the crop value estimates were completed for the counties where damage to vegetation seemed likely to occur as a result of air pollutants.

4. Estimates of the potential annual value of forests and the annual maintenance costs of ornamental plantings were completed. To complete these estimates, it was necessary to determine the dollar values for the states (in most instances, the only data available) and then to prorate this value to the polluted counties on the basis of their proportionate area, population, or combination of area and population of the state. Separate estimates were made for oxidant-, sulfur dioxide-, and fluoride-polluted counties. Similarly, these valuations were made for commercial and noncommercial forests, and for the ornamentals found on the grounds of educational institutions, industrial parks, golf courses, roadside landscaping, private residences, and city, county, state and sectional parks.

5. Tables showing the relative sensitivity of different plant species to oxidants, sulfur dioxide and fluorides were prepared and updated as a result of a continuing literature review. From these relative sensitivities, tables were prepared indicating, for each pollutant, the percentage loss that might be expected to crops and ornamental plantings in the most severely polluted counties.

6. With this table as background, tables were then prepared showing the percentage loss that might be expected to crops and ornamentals in counties in the different pollution classes described in Item 2 above. Obviously, information was not available on all the crops for the three major pollutants. However, loss factors were compiled for 62 species or groups of species for oxidant exposures, 63 for sulfur dioxide exposures, and 36 for fluoride exposures.

7. These factors were then applied to value of the crops, forests, and ornamentals grown in the polluted counties, and the dollar loss value for each crop in each county was recorded. These values were added to obtain the state, regional, and national values.

8. The estimates derived were then compared with similar estimates made for California and Pennsylvania as a result of on-the-spot surveys by agricultural experts in the respective states.

The various steps for estimating dollar loss value may be summarized as follows:

Oxidants

$$\text{Emissions}^* \times \frac{\text{Concentration}^\dagger}{\text{Rate Factor}} \times \text{Area}^\ddagger \times \text{Episode Days}^\S = \text{Pollution Potential (7 classes)}$$

Sulfur Dioxide

$$\left. \begin{array}{l} \text{Emissions} \times \frac{\text{Concentration}}{\text{Rate Factor}} \times \text{Area} \times \text{Episode Days} \\ + \\ \text{Emissions from various types and sizes of large single sources} \end{array} \right\} = \text{Pollution Potential (6 classes)}$$

Fluorides

$$\text{Emissions from various types and sizes of large single sources} = \text{Pollution Potential (4 classes)}$$

Oxidants, Sulfur Dioxide and Fluorides

$$\text{Crop Value} \times \text{Crop Sensitivity} \times \text{Pollution Potential} = \text{Dollar Loss}$$

$$\text{Ornamental Value} \times \text{Ornamental Sensitivity} \times \frac{\text{Pollution Potential}}{\text{Potential}} = \text{Dollar Loss}$$

* Tons of hydrocarbons or oxides of nitrogen emitted per square kilometer per day.

† A factor indicative of the tendency of climatic conditions to concentrate pollutants during an air-stagnation period. See text for further explanation.

‡ Square of the radius of the SMSA, assuming the area is circular.

§ Number of days occurring in stagnation periods of two or more successive days.

As a result of the various investigations described above, 551 of the 3,134 counties in the United States were selected as having potential plant-damaging exposure to oxidants, sulfur dioxide and fluorides. Of these, 327 would be exposed to oxidants, 336 to sulfur dioxide, and 86 to fluorides. (Some counties would be exposed to two or more.) On the basis of area and population in these counties, it was estimated that about 9% of the area and 62% of the population occurred in counties likely to have plant-damaging oxidant pollution. The respective values were 13% and 54% for sulfur dioxide and 4% and 9% for fluorides. It was further calculated that 27% of the dollar value of crops grown in the United States occurred in the 551 pollution-threatened counties. The highest percentages were found in the Middle Atlantic States and the lowest in the West North Central States.

Based on estimates of losses found to occur to various crops and ornamentals in the most severely polluted counties, tables were prepared showing the factors to be applied to values of crops and ornamentals grown in the different classes of counties. This procedure gave the estimated loss to a specific crop in the various counties due to oxidants, sulfur dioxide or fluorides.

The values of crops grown in the various counties had been previously compiled except for grass hay and pastures, which were calculated during the past year. The estimated values were \$166 million for pastures and \$12 million for grass hay in counties where a fluoride pollution potential existed.

The total potential annual value for commercial forests in the polluted counties was estimated to be about \$130 million, with California having the highest value and North Dakota the lowest.

The total maintenance values for ornamental plantings in the polluted counties were estimated to be \$1,281 million for the United States. The values for the various categories were: cemeteries, educational institutions, industrial parks, and golf courses, \$452 million; roadside landscaping, \$31 million; city, county, state and national parks, \$194 million; private residences, \$604 million.

When the loss factors for the various pollution intensities were applied to the crop and ornamental values, the total annual dollar loss to crops in the United States was calculated to be about \$85.5 million, of which \$78 million was due to oxidants, \$3.25 million to sulfur dioxide, and \$4.25 million to fluorides. The loss to ornamentals was calculated to be about \$46 million, of which \$43 million was ascribable to oxidants, \$3 million to sulfur dioxide, and \$175 thousand to fluorides.

The SRI estimates of crop loss in California fell between two such yearly loss estimates developed from on-the-spot estimates by the California Department of Agriculture. Loss estimates for Pennsylvania for two years were compiled by the Center for Air Environment Studies of Pennsylvania State University from on-the-spot surveys by trained observers.

The SRI loss estimates for Pennsylvania were somewhat higher in one year and substantially higher in the second year than the estimates made by the Pennsylvania group. These comparisons seem to indicate that the loss levels estimated in this report are reasonable; if anything, they may be high--at least for oxidants.

One of the minor objectives of this report was to arrive at some estimate of amounts of loss occurring that might be ascribable to auto exhausts. This depends on whether oxides of nitrogen or hydrocarbons are more important in determining the amount of ozone and PAN produced in the atmosphere. If oxides of nitrogen are the important feature, then the automobile may be responsible for about \$30 million of the crop loss, or approximately 35%; if hydrocarbons are the important compounds, they could be responsible for \$60 million of the crop loss for the country as a whole. These ratios would be different in different sections of the country. For example, the automobile contribution to hydrocarbons is much lower in the eastern part of the United States than on the West Coast.

The greatest percentage of loss due to pollutants occurred in the heavily industrialized areas of the Middle Atlantic and East North Central States. The lowest amount of loss occurred in the West North Central States, i.e., Missouri, Iowa, Kansas, Nebraska, Minnesota and the Dakotas.

The dollar loss as a percentage of the total dollar value of all commercial crops grown in the United States was about 0.5%. Losses due to plant diseases and insects have been placed at 10-12% and those due to weeds, at 6-8%. Estimates of losses due to these pests are not available for ornamentals.

In conclusion, it must be pointed out that although the loss estimates presented in this report seem valid, they are still only estimates and, as such, are subject to revision when more reliable sources of information become available.

III METHODS AND RESULTS

The same general plan of work was followed in the second year as in the first, except that no further effort was made to develop methods of estimating losses based on experience of investigators in other fields. Previous discussion and studies had indicated that there was no simple method and that, to be reliable, estimates almost had to be made from personal observation and experience. The other phases of the work plan were followed. The data from which the emissions of hydrocarbons and oxides of nitrogen were calculated are for the year 1963. The crop production by county was taken from the 1964 Census of Agriculture.¹ These were the latest data available at the time these studies were initiated.

The order in which the results are presented has been changed to that given below:

Pollutants Involved

Nature
Relative intensity of pollution
Regional distribution of pollution

Vegetation Occurring in Polluted Areas

Crops

Types
Yield
Dollar value

Forests

Yield
Dollar value

Ornamental Plantings

Types
Replacement and maintenance costs

Sensitivity of Various Species to the Specific Pollutants

Relative sensitivity
Percentage yield loss under severest condition

Formulae for Calculating Dollar Loss Due to Pollutants

Dollar Loss

By pollutant
By crop
By area

Pollutants Involved

The compounds in the atmosphere that cause the greatest damage to vegetation, either directly by reduced yield and growth or indirectly by their effect on the quality of the crop, are:

Ozone
Peroxyacetyl nitrate (PAN)
Oxides of nitrogen
Sulfur dioxide
Fluorides

Since these pollutants produce well over 90% of the losses to vegetation caused by air pollutants, this study has been confined to their effects. However, two of the pollutants--ozone and PAN--are formed as a result of photochemical reactions between hydrocarbons and oxides of nitrogen and are not emitted directly into the atmosphere. Controlled experiments have not given definitive answers as to whether oxidant concentrations developing as a result of the interaction are more readily related to the hydrocarbons or to the oxides of nitrogen concentration. However, it has been possible to demonstrate a relationship between the maximum oxidant level reached in any one day and the hydrocarbon concentration in the atmosphere between 6:00 and 9:00 a.m.² Therefore, hydrocarbons were used in estimating the relative severity of oxidant pollution. But a review of the ratings based on oxides of nitrogen shows that there would be only minor changes in the relative ratings assigned, the most notable changes being a decrease in the estimated relative severity of pollution in West Coast cities, such as San Jose, Portland and Seattle, and a slight increase in the large eastern cities.

Intensity of Pollution and Location of Polluted Areas

In the 1970 report, counties were listed where air pollution problems seemed likely to exist, based primarily on population density (Standard Metropolitan Statistical Areas) for ozone, PAN, oxides of nitrogen and sulfur dioxide, and on industrial operations for sulfur dioxide and fluorides. Estimates of emission of hydrocarbons, oxides of nitrogen, and sulfur dioxide in the SMSAs were calculated from fuel consumption in those areas. These emission values were expressed simply as the total number of tons per day by county, not by unit area. Such forms of expression did not take into account the area over which the pollutants might be emitted or the effect of meteorological conditions in either dispersing or concentrating the emissions. Consequently, some revisions were made in these estimates, as follows.

SRI's hydrocarbon estimates were observed to be lower than other estimates where such comparisons could be made (Los Angeles County, for example). It was subsequently determined that these lower values were due to an improper factor applied to gasoline consumption to provide figures for hydrocarbon emissions. An appropriate change in this factor

increased the figure for hydrocarbon emissions from auto exhausts by 70%. The hydrocarbon emissions for SMSAs were therefore recalculated.

Estimates of hydrocarbons, oxides of nitrogen, and sulfur dioxide have now been expressed in tons per unit area per day rather than as simple total emissions per day or year. The results, in tons per day per square kilometer, are shown in Columns 2, 3, and 4 of Table 1.

A recent paper by Holzworth³ derives concentration rate factors due to meteorological conditions. These rate factors, designated as $\bar{x}/\bar{q}$ and expressed as seconds per meter, are a measure of the tendency of meteorological conditions to affect the concentration of pollutants emitted to the atmosphere. Thus,

$$\bar{x}/\bar{q} = \frac{\text{time}}{\text{height}} \quad \text{emission} = \frac{\text{weight}}{\text{time} \times \text{area}}$$

$$\frac{\text{time}}{\text{height}} \times \frac{\text{weight}}{\text{time} \times \text{area}} = \frac{\text{weight}}{\text{volume}} = \text{concentration}$$

The Holzworth paper presents a map showing how these concentration rate factors vary in different parts of the United States. This map is essentially reproduced in Figure 1. The relative concentration rate factors for the various SMSAs are given in Column 5 of Table 1. However, in the table, $\bar{x}/\bar{q}$ values of 0-19 are designated as 1, 20-39 as 2, 40-59 as 3, 60-79 as 4, and 80 and over as 5.

Holzworth's paper further indicates that the size of the area over which the emissions are occurring also affects the ultimate concentration. The areas of the SMSAs are given in City and County Data Book, 1962, U.S. Dept. of Commerce.⁴ It was assumed that these areas were circular, and the radius of each was calculated. The calculated radii were then assigned relative values as follows: 5-14 km = 1, 15-24 km = 2, 25-34 km = 3, etc. These relative radii values are given in Column 6 of Table 1.

The Holzworth paper also presents a map showing the number of days in a five-year period that were included in atmospheric stagnation periods of at least two days' duration. These isopleths, which are indicative of the relative number of days that might be included in pollution episodes occurring in each SMSA in five years, have been replotted in Figure 2. These values for each SMSA have also been listed in Column 7 of Table 1.

By multiplying the emission of each pollutant by the relative $\bar{x}/\bar{q}$ values by the radius of the SMSA (Column 2, 3 or 4 by Column 5 by Column 6, Table 1), a value is obtained indicating the relative concentration that might occur during any pollution episode. When this product is multiplied by the number of episode days (Column 7, Table 1), a value representing the overall relative severity of plant-damaging pollution for each SMSA is obtained. These overall pollution values for hydrocarbons, oxides of nitrogen, and sulfur dioxide are shown in Table 2.

Table 1

**BASIC DATA FOR CALCULATING RELATIVE AIR POLLUTION POTENTIAL IN
DIFFERENT SMSAs BASED ON EMISSIONS AND WEATHER FACTORS**

SMSA (1)	Emissions (tons/km ² /day)			Weather Factors		
	Hydro- carbons (2)	Oxides of Nitrogen (3)	Sulfur Dioxide (4)	$\bar{x}/\bar{q}^a$ Value (5)	Radius Value ^b (6)	Episode Days ^c (7)
Akron	0.047	0.034	0.132	3	3	50
Albany - Schenectady - Troy	.0205	.024	0.098	4	4	25
Allentown - Bethlehem - Easton	.028	.025	0.146	3	3	25
Atlanta	.046	.021	0.061	2	4	50
Baltimore	.054	.048	0.257	4	4	50
Birmingham	.033	.035	0.081	4	3	75
Boston	.142	.217	0.410	2	3	25
Bridgeport	.127	.073	0.086	2	1	25
Buffalo	.044	.029	0.092	2	4	50
Canton	.039	.024	0.068	3	2	50
Chattanooga	.0200	.0089	0.029	4	3	75
Chicago	.098	.0703	0.309	3	6	50
Cincinnati	.029	.029	0.162	3	4	75
Cleveland	.078	.052	0.159	2	4	50
Columbus	.038	.015	0.025	3	4	50
Dallas	.024	.012	0.00077	2	5	1
Dayton	.029	.019	0.078	2	4	25
Denver	.017	.0077	0.028	2	5	100
Detroit	.138	.088	0.310	2	4	50
Flint	.024	.0093	0.024	3	3	50
Ft. Worth	.027	.014	0.00077	2	4	1
Gary - Hammond - E. Chicago	.044	.058	0.238	3	3	50
Grand Rapids	.023	.012	0.043	3	3	25
Greensboro - High Point	.026	.0089	0.016	3	2	50
Hartford	.068	.031	0.097	2	2	25

Table 1 (continued)

SMSA (1)	Emissions (tons/km ² /day)			Weather Factors		
	Hydro- carbons (2)	Oxides of Nitrogen (3)	Sulfur Dioxide (4)	$\bar{x}/q^a$ Value (5)	Radius Value ^b (6)	Episode Days ^c (7)
Houston	0.018	0.015	0.000502	2	7	25
Indianapolis	.026	.014	0.065	2	5	50
Jersey City	.633	.725	3.360	2	1	25
Kansas City	.029	.014	0.016	2	5	25
Lancaster	.018	.012	0.054	4	3	50
Lawrence - Haverhill	.163	.073	0.304	2	1	25
Los Angeles - Long Beach	.120	.059	0.024	3	6	300
Louisville	.055	.056	0.286	3	3	75
Memphis	.017	.020	0.038	4	3	75
Miami	.033	.014	0.010	1	4	25
Milwaukee	.074	.051	0.278	3	3	50
Minneapolis - St. Paul	.051	.027	0.065	4	4	25
Nashville	.021	.017	0.097	4	4	50
New Haven	.083	.052	0.153	2	1	25
New Orleans	.025	.021	0.00058	2	4	100
New York	.205	.132	0.539	2	4	25
Newark	.149	.095	0.377	2	2	25
Paterson - Clifton - Passaic	.186	.096	0.382	2	2	25
Philadelphia	.039	.042	0.215	3	5	50
Pittsburgh	.045	.059	0.263	4	5	50
Portland	.014	.00502	0.108	4	5	200
Providence	.062	.039	0.179	2	2	25
Reading	.025	.025	0.198	3	3	50
Richmond	.026	.019	0.107	3	3	50
Rochester	.017	.0093	0.046	2	4	50
St. Louis	.051	.025	0.113	2	6	50
San Diego	.015	.069	0.00208	4	6	400
San Francisco - Oakland	.069	.038	0.019	3	5	300
San Jose	.039	.012	0.0012	3	3	300
Seattle	.017	.0062	0.017	2	6	100

Table 1 (concluded)

SMSA (1)	Emissions (tons/km ² /day)			Weather Factors		
	Hydro- carbons (2)	Oxides of Nitrogen (3)	Sulfur Dioxide (4)	$\bar{x}/\bar{q}$ ^a Value (5)	Radius Value ^b (6)	Episode Days ^c (7)
Springfield	0.046	0.035	0.215	2	2	25
Syracuse	.014	.0085	0.041	3	4	50
Toledo	.028	.017	0.063	2	4	50
Utica - Rome	.00734	.0031	0.014	3	5	50
Washington, D. C.	.081	.035	0.128	4	4	50
Wichita	.019	.012	0.00506	2	4	25
Wilmington	.032	.024	0.094	3	3	50
Worcester	.065	.025	0.080	2	2	25
York	.013	.014	0.082	4	3	50
Youngstown	.031	.029	0.086	3	3	50

a. Holzworth³ presents factors of $\bar{x}/\bar{q}$ = seconds per meter of values 0-20, 21-40, 41-60, 61-80, 81+ for cities with a radius of at least 10 km. For comparative purposes, these have been designated 1, 2, 3, 4, and 5, respectively.

b. The distance over which the pollutants pass is related to the total concentration build-up, so radii of metropolitan areas are designated as follows: 5-14 km = 1, 15-24 km = 2, 25-34 km = 3, etc.

c. Number of days in a five-year period of limited dispersion.

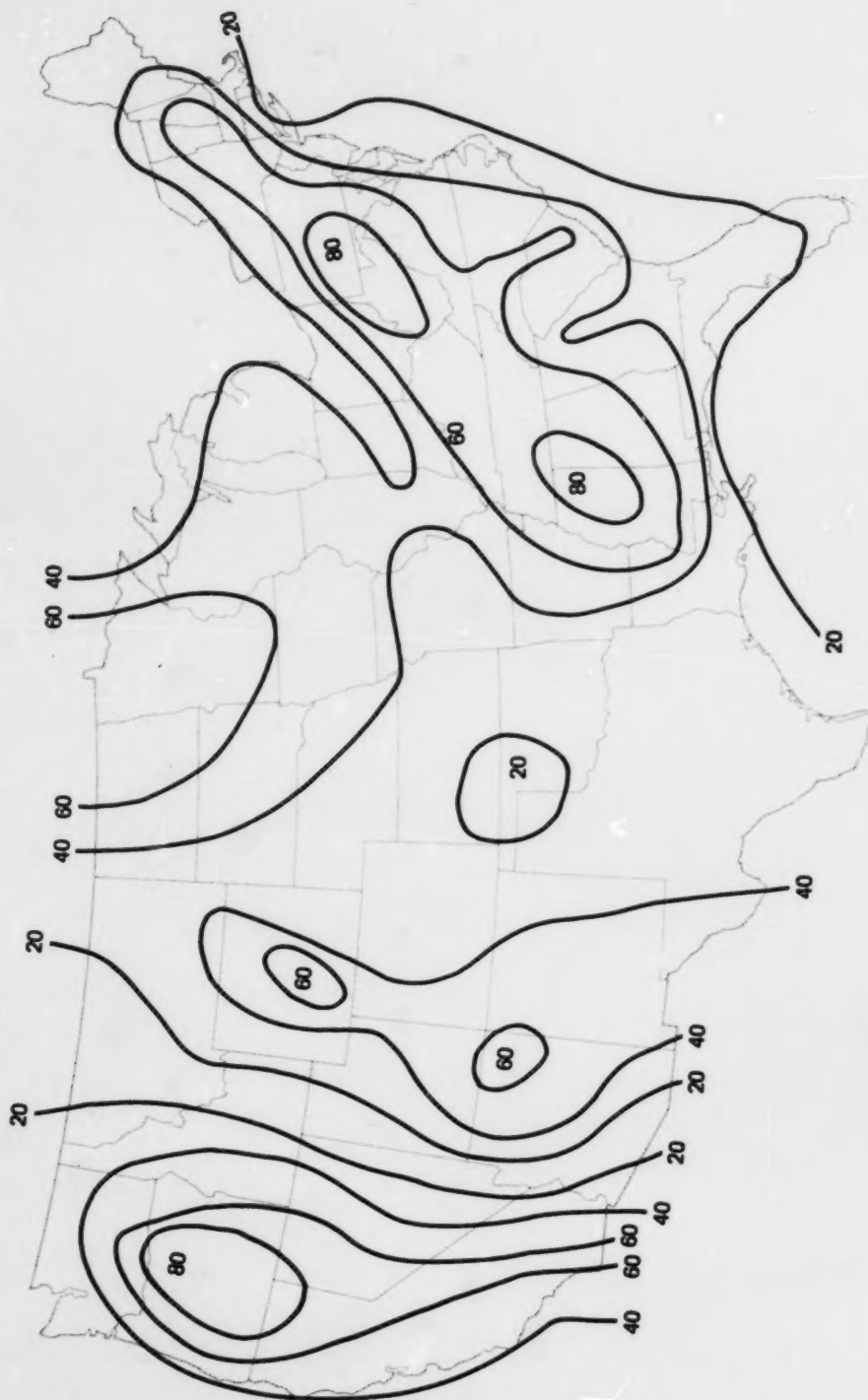


FIGURE 1 ISOPLETHS FOR THE CONCENTRATION RATE FACTOR $\bar{x}/\bar{q}$ EXCEEDED ON 10 PERCENT OF MORNINGS ANNUALLY FOR 10-km CITY SIZES

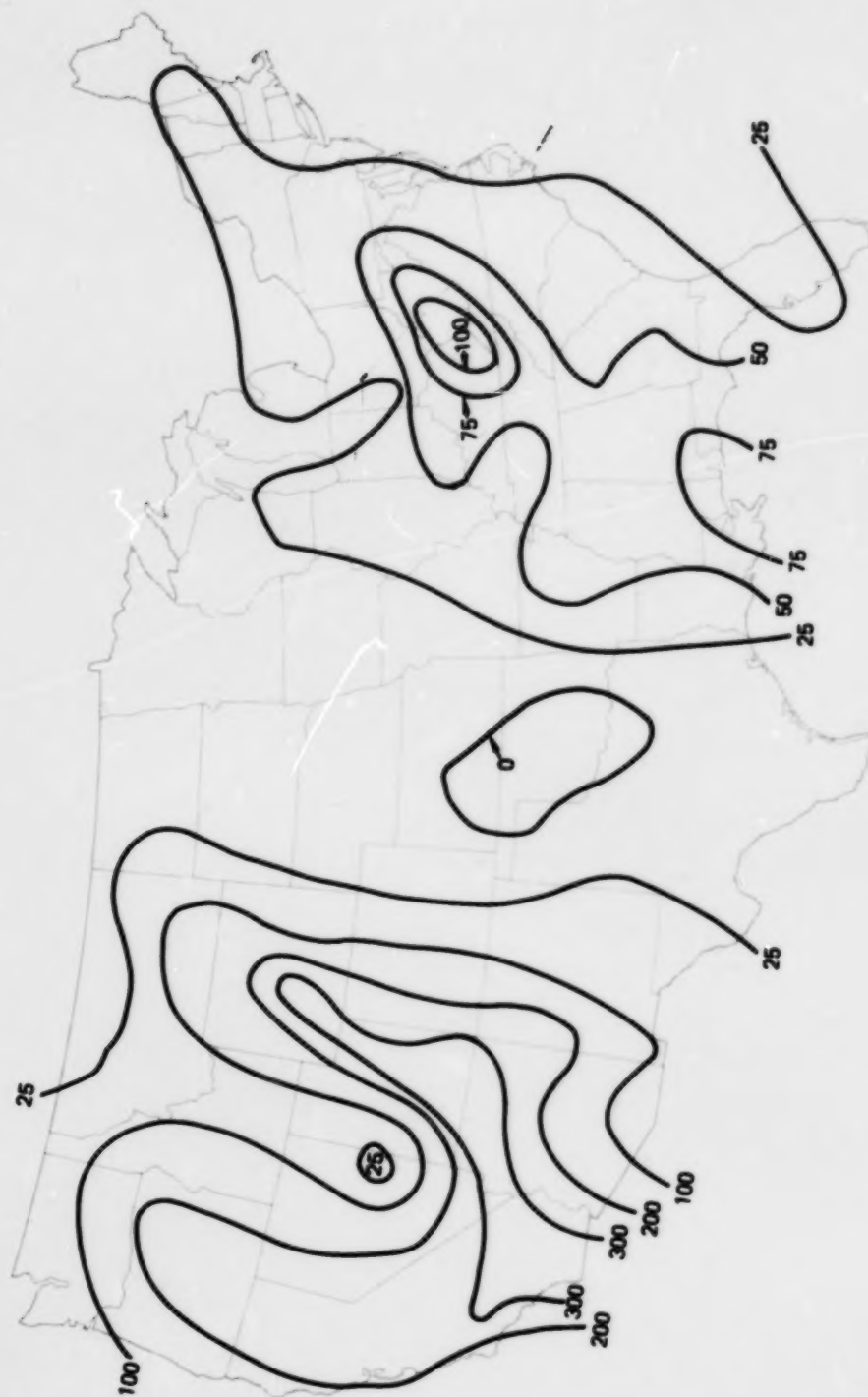


FIGURE 2 ISOPLETHS OF THE NUMBER OF DAYS IN PERIODS OF STAGNATION OF AT LEAST TWO DAYS OVER A FIVE-YEAR PERIOD

Table 2

RELATIVE AIR POLLUTION POTENTIAL IN DIFFERENT SMSAs BASED ON EMISSION
TIMES CONCENTRATION FACTOR TIMES NUMBER OF STAGNATION PERIODS

<u>SMSA</u>	<u>Relative Potential</u>	<u>SMSA</u>	<u>Relative Potential</u>
<u>Hydrocarbons</u>		<u>Hydrocarbons (continued)</u>	
Los Angeles - Long Beach	648	Paterson - Clifton -	
San Francisco - Oakland	311	Passaic	19
San Diego	144	Atlanta	18
San Jose	105	Chattanooga	18
Chicago	88	Buffalo	18
Washington, D.C.	65	Denver	17
Portland	56	Nashville	17
Detroit	52	Memphis	15
Jersey City	48	Newark	15
Pittsburgh	45	Wilmington	14
Baltimore	43	Youngstown	14
New York	41	Indianapolis	13
Louisville	38	Canton	12
Milwaukee	33	Richmond	12
Cleveland	31	Reading	11
St. Louis	31	Toledo	11
Birmingham	30	Flint	11
Philadelphia	29	Lancaster	11
Cincinnati	26	Syracuse	8
Columbus	23	Albany - Schenectady -	
Boston	21	Troy	8
Akron	21	Lawrence - Haverhill	8
Seattle	20	Greensboro - High Point	8
Minnesota - St. Paul	20	York	8
New Orleans	20	Kansas City	7
Gary - Hammond -		Hartford	7
E. Chicago	20		

Table 2 (continued)

<u>SMSA</u>	<u>Relative Potential</u>	<u>SMSA</u>	<u>Relative Potential</u>
<u>Hydrocarbons (concluded)</u>		<u>Oxides of Nitrogen (continued)</u>	
Rochester	7	Cincinnati	26
Worcester	7	Gary - Hammond -	26
Bridgeport	6	E. Chicago	23
Allentown - Bethlehem -		Milwaukee	21
Easton	6	Cleveland	21
Houston	6	Portland	18
Providence	6	Memphis	17
Dayton	5	New Orleans	15
Utica - Rome	5	Akron	15
Grand Rapids	5	St. Louis	14
Springfield	4	Nashville	13
New Haven	4	Youngstown	12
Wichita	3	Buffalo	11
Miami	< 1	Reading	11
Dallas	< 1	Minneapolis - St. Paul	11
Ft. Worth		Wilmington	11
<u>Oxides of Nitrogen</u>		Paterson - Clifton -	10
Los Angeles - Long Beach	319	Passaic	10
San Francisco - Oakland	171	Albany - Schenectady -	10
San Diego	66	Troy	10
Chicago	63	Newark	9
Pittsburgh	59	Columbus	9
Jersey City	54	Richmond	8
Baltimore	38	York	8
Louisville	37	Atlanta	8
Detroit	35	Chattanooga	8
Boston	32	Denver	7
San Jose	32	Seattle	7
Philadelphia	32	Canton	7
Birmingham	32	Lancaster	7
Washington, D.C.	28	Indianapolis	7
New York	26	Toledo	6
		Allentown - Bethlehem -	
		Easton	

Table 2 (continued)

<u>SMSA</u>	<u>Relative Potential</u>	<u>SMSA</u>	<u>Relative Potential</u>
<u>Oxides of Nitrogen (concluded)</u>		<u>Sulfur Dioxide (continued)</u>	
Houston	5	New York	108
Syracuse	5	Gary - Hammond	107
Flint	4	Washington, D.C.	102
Providence	4	Reading	89
Dayton	4	San Francisco - Oakland	86
Rochester	4	Nashville	78
Lawrence - Haverhill	4	Birmingham	72
Bridgeport	4	St. Louis	68
Springfield	4	Cleveland	64
Kansas City	4	Boston	62
Hartford	3	Akron	59
Grand Rapids	3	York	49
Greensboro - High Point	3	Richmond	48
New Haven	3	Portland	44
Worcester	3	Wilmington	42
Wichita	2	Albany - Schenectady -	
Utica - Rome	2	Troy	39
Miami	1	Youngstown	39
Dallas	<1	Paterson - Clifton -	
Ft. Worth	<1	Passaic	38
		Newark	38
		Buffalo	37
<u>Sulfur Dioxide</u>			
Chicago	278	Memphis	34
Pittsburgh	263	Allentown - Bethlehem -	
Jersey City	252	Easton	33
Baltimore	206	Indianapolis	33
Louisville	193	Lancaster	32
Philadelphia	161	Denver	28
Cincinnati	146	Chattanooga	27
Los Angeles - Long Beach	130	Minneapolis - St. Paul	26
Milwaukee	125	Toledo	25
Detroit	124	Syracuse	25
		Atlanta	24

Table 2 (concluded)

<u>SMSA</u>	<u>Relative Potential</u>
<u>Sulfur Dioxide (concluded)</u>	
Springfield	22
Canton	20
Seattle	20
San Diego	20
Rochester	18
Providence	18
Dayton	16
Lawrence - Haverhill	15
Columbus	15
Flint	11
Utica - Rome	11
Hartford	10
Grand Rapids	10
Worcester	8
New Haven	8
Greensboro - High Point	5
Bridgeport	4
Kansas City	4
San Jose	3
Wichita	1
New Orleans	<1
Houston	<1
Miami	1
Ft. Worth	<1
Dallas	<1

Thus calculated, the data indicate that Los Angeles is much above any other area in terms of potentially high atmospheric concentrations of hydrocarbons and oxides of nitrogen, and that the West Coast cities show potential pollution greater than would be expected based on size alone.

In terms of sulfur dioxide emissions, Chicago seems to have the greatest potential for pollution. In general, the big industrial cities of the Eastern and Central States (New York, Pittsburgh, Louisville, Cincinnati, Detroit and Chicago) appear to have a potential for sulfur dioxide pollution much greater than that for the West Coast cities, except in some cases for Los Angeles.

Table 2 gives the relative potential pollution intensity for various hydrocarbons, oxides of nitrogen, and sulfur dioxide in various SMSAs throughout the country. As indicated earlier, the hydrocarbons and oxides of nitrogen react to form ozone and PAN. Oxides of nitrogen themselves may produce some injury. Since it is difficult to separate the effects of ozone, PAN, and oxides of nitrogen, they have been lumped together under the term "oxidants" as a causative agent. The SMSAs include most counties where injury due to photochemical smog is likely to occur. However, there are other sources of sulfur dioxide in isolated areas that emit plant-damaging amounts; these sources, as well as sources of vegetation-damaging fluorides, were not included in the SMSA data in Tables 1 and 2.

In the 1970 Annual Report (Volume I), Table 6 listed, by state and county, the types of activity that contribute to the five pollutants under consideration. The table indicated whether or not the county was in an SMSA and showed the number of iron and steel mills, power plants with over 100-kw capacity, oil refineries with a capacity over 20,000 barrels per day, copper, lead and zinc smelters, and phosphorus, phosphate and aluminum plants, all of which are major emitters of sulfur dioxide and fluorides. More than 550 counties were tabulated by state, and their respective areas and populations were calculated as a percentage of the state total and United States total. These values (shown in Table 5) were useful in calculating dollar value of various ornamental crops, as described later. However, very often several counties were subjected to all five pollutants or perhaps only one of them. To obtain a better idea of the regional distribution of the areas in which plant-damaging pollution seemed likely to occur, the areas (miles²) of the counties polluted by the different pollutants in the various main geographic sections of the country were calculated as well as the percentage of the total area of the region containing the selected counties. Similar values were calculated for the number of people residing in these counties. These data are shown in Table 3. The states included in the various regions are as follows:

Table 3

TOTAL AREA AND POPULATION OF POLLUTION-THREATENED COUNTIES AS A PERCENTAGE
OF THE RESPECTIVE TOTALS IN VARIOUS GEOGRAPHICAL REGIONS OF THE UNITED STATES

Region	Total Area (000 sq mi)	Pollution-Threatened Area					
		Thousand Square Miles			Percent of Total Area		
		Oxidants ^a	SO ₂	Fluorides	Oxidants	SO ₂	Fluorides
New England	63.0	13.8	11.0	0.0	21.9	17.5	0.0
Middle Atlantic	100.4	31.3	28.7	2.6	31.2	28.6	2.6
East North Central	244.4	39.7	50.6	7.8	16.2	20.7	3.2
West North Central	507.3	28.4	48.8	4.5	5.6	9.6	0.9
South Atlantic	267.5	34.9	41.9	10.2	13.1	15.6	3.8
East South Central	179.4	14.2	20.0	3.7	7.9	11.1	2.1
West South Central	429.3	37.9	50.9	11.3	8.8	11.9	2.6
Mountain	856.6	50.5	133.3	29.5	5.9	15.6	3.4
Pacific	319.4	81.8	71.1	56.7	25.6	22.3	17.8
Hawaii	6.4	0.6	0.6	0.0	9.4	9.4	0.0
Alaska	566.4	0.0	0.0	0.0	0.0	0.0	0.0
	3,540.1	333.1	456.9	126.3	9.4	12.9	3.6

Region	Total Population (millions)	Population of Pollution-Threatened Counties					
		Millions			Percent of Total Population		
		Oxidants	SO ₂	Fluorides	Oxidants	SO ₂	Fluorides
New England	10.5	8.6	7.5	0.0	81.9	71.4	0.0
Middle Atlantic	34.2	25.7	23.0	0.7	75.1	67.3	2.0
East North Central	36.2	24.5	21.8	4.0	67.7	60.2	11.0
West North Central	15.4	5.7	5.9	1.7	37.0	38.3	11.0
South Atlantic	26.0	12.8	10.9	2.5	49.2	41.9	9.6
East South Central	12.1	4.8	3.8	0.3	39.7	31.4	2.5
West South Central	17.0	8.6	7.6	2.1	50.6	44.7	12.4
Mountain	6.9	3.3	3.0	0.9	47.8	43.5	13.0
Pacific	20.3	16.2	12.7	4.2	79.8	62.6	20.7
Hawaii	0.6	0.5	0.5	0.0	83.3	83.3	0.0
Alaska	0.2	0.0	0.0	0.0	0.0	0.0	0.0
	179.4	110.7	96.7	16.4	61.7	53.9	9.1

a. O₃, PAN, and NO_x.

New England:	Maine, Vermont, New Hampshire, Massachusetts, Rhode Island, Connecticut
Middle Atlantic:	New York, New Jersey, Pennsylvania
East North Central:	Ohio, Indiana, Illinois, Michigan, Wisconsin
West North Central:	Missouri, Iowa, Minnesota, Kansas, Nebraska, South Dakota, North Dakota
South Atlantic:	Delaware, Maryland, West Virginia, District of Columbia, Virginia, North Carolina, South Carolina, Georgia, Florida
East South Central:	Kentucky, Tennessee, Alabama, Mississippi
West South Central:	Arkansas, Louisiana, Oklahoma, Texas
Mountain:	Montana, Wyoming, Colorado, New Mexico, Arizona, Nevada, Utah, Idaho
Pacific:	California, Oregon, Washington, Hawaii

As would be expected, the highest percentages of land in counties with oxidant or sulfur dioxide pollution sources are found in the heavily populated, industrialized regions--the Middle Atlantic, New England, East North Central, and Pacific. The lowest percentage of land involved in oxidant pollution is in the agricultural areas such as the West North Central. In general, the areas in counties where SO_2 sources are present are larger than those containing oxidant sources. This difference is surprisingly large, however, in the Mountain region. This is due to the large number of copper, lead, or zinc smelters in that region; these smelters emit sulfur dioxide but are not main sources of oxidants.

The area exposed to sulfur dioxide fumigations is found in counties that constitute about 12.9% of the land area of the United States; the corresponding value for oxidants is 9.4% and for fluorides, 3.6%. Most of the fluoride-fumigated area is found in the State of Washington because of the large number of aluminum plants.

Although the land area over which plant-damaging concentrations of oxidants might be found is only 9.4% of the area of the United States, 62% of the population resides in these counties. This means that although crop production may be low, the value of ornamental plantings around homes, parks, etc. will be correspondingly high. This relation between ornamental plantings and population was the only reason for presenting these figures.

Many of the counties involved were both in a metropolitan statistical area and had sulfur dioxide sources. If only the significant sources of SO_2 outside the SMSA are considered, the area is cut about in half (to 6.7%) and the population involved drops from 53.9% to 6.4% on a nationwide basis. This method of calculating eliminated most of the power plant sources, which are so closely tied up with power requirements of large

population centers, and left mostly large industrial sources such as iron and steel plants, nonferrous smelters, and oil refineries.

In general, these data show that the air pollution of concern is centered in the heavily populated areas. Fluoride is an exception in that counties with fluoride sources seem to be in less densely populated areas. This is true because the major fluoride-emitting sources are constructed where electrical power is plentiful.

Value of Vegetation Occurring in Polluted Areas

Commercial Crops

To estimate dollar loss due to air pollutants, it is necessary to know the dollar value of the vegetation and the percentage loss that may be ascribed to the pollutant. The dollar value of commercial crops growing in the potentially polluted counties was given by county in the 1970 Annual SRI Report (Vol. II), based on data available from the 1964 Census of Agriculture. This value was based on the prices paid the farmer. No adjustment has been made in prices on any assumed basis of shift in the effective supply curve due to the smaller supplies being available to the market as a result of the pollution loss. Such an adjustment would be difficult to make with any degree of accuracy.

Air pollution increases production costs in commercial agriculture, thus affecting both producer and consumer. The effect on the producer will be greater in a heavily polluted area than in an area where there is only light pollution, as the production costs per ton of crop harvested will be much higher in the heavily polluted area. In the same way, unit production costs of crops that respond more sharply to a certain degree or kind of air pollution in an area will be higher than unit production costs of crops that show little or no response to the pollution.

The burden of increased costs due to pollution will ordinarily be shared between producer and consumer. To the extent that the supply curve for a crop is elastic and the demand curve is inelastic, in a year when there is a smaller crop than normal, then pollution may force the consumer to absorb most of the increased costs. If the crop is larger than normal, then pollution costs may have to be absorbed almost entirely by the producer, as market prices will not rise higher than normal. If the demand for a crop is relatively more elastic than the supply, however, then the producer will have to bear most of the burden of increased costs in any case.

The 1967 cost at retail of the "farm food market basket" was \$1,080; the farm value of the same commodities was \$414.⁵ Consequently, the increase in retail value over farm prices amounted to 161%. While all the discussions of crop values and pollution loss values that follow are based on farm prices, the reader should not forget that the value

of crops at the consumer level could also have been used, with equal validity, and in that case the absolute level of the values would have been increased very substantially.

It is not necessary to report again the figures given in the 1970 report, but the dollar value of commercial crops in potentially polluted counties in different regions of the United States, the value in the entire region, and the percentage the polluted value is of the total are shown below.

Region	Value in Polluted Area	Value in Total Area	Percent
New England	\$ 106,000,000	\$ 326,000,000	33
Middle Atlantic	481,000,000	768,000,000	63
East North Central	1,091,000,000	2,708,000,000	40
West North Central	385,000,000	2,751,000,000	14
South Atlantic	498,000,000	3,449,000,000	14
East South Central	196,000,000	1,127,000,000	17
West South Central	466,000,000	2,353,000,000	20
Mountain	301,000,000	1,011,000,000	30
Pacific	1,125,000,000	3,607,000,000	31
	\$4,649,000,000	\$18,100,000,000	27

Thus, in the heavily industrialized Middle Atlantic and East North Central States, the value of crops grown in areas where air pollution is likely to occur represents 45% of the total value of the crops grown in those regions. However, in the heavily agricultural areas of the central and southern states, the value of crops grown in polluted counties represents about 15% of the total value of the crops produced, and the total value in this area represents about 60% of the United States total. The West Coast area is a highly productive one and, because of meteorological conditions as well as actual pollution emissions, the value of the crops subject to pollution is a greater proportion of the total value than is usual for agricultural areas.

Although values for commercial crops were given in the 1970 report, values were not obtained for other types of vegetation susceptible to pollution damage, namely, grass hay and pastures, forests, and ornamental plantings. Values for these types of vegetation were derived as follows.

Grass Hay and Pastures. Although the yield of these forages may not be affected, fluoride contamination of them may render them useless as feed because of the effect on the animals consuming them; therefore, to estimate the losses due to fluorides, it is necessary to know the value of grass hay and pastures. For this reason, the value of these crops was determined only for the counties where significant fluoride sources existed. In the Census of Agriculture, values of grass hay and

pastures are not specifically itemized although acreages are reported as well as hay yields. These values plus those for grass silage were converted to hay equivalents for convenience in making the estimates. The estimated values are shown in Table 4.

Forests and Ornamentals

Estimates of the value of the various "types" of vegetation in the potentially polluted counties were based on national or state-wide data. Such data were often not available by county; hence, the state data had to be broken down into county estimates through the use of indexes. The derivation of three such indexes is shown in Table 5; one is based on population, one on geographic area, and the third on a combination of the other two. In discussing each "type" of vegetation, the use of one of these three indexes will be indicated.

Forests

Commercial forest. "Commercial forest" land is defined as forested land capable of producing crops of industrial wood and by-products, in both accessible and inaccessible areas. "Forest products" include cut timber plus materials produced and sold from the forest that are not measurable in board feet, such as tanbark, turpentine, seedlings, Spanish moss, and other products.

The last complete census of the Forest Service was in 1962, when the commercially forested acreage within national forests totaled approximately 97 million acres.⁶ The reported total value of forest products sold for that year from national forests was approximately \$135 million. If the same national forest acreage is assumed for 1964 and the actual 1964 sale value of forest products (\$162 million) is applied to that acreage, the value per acre would be \$1.67. However, the average value of forest products available for sale annually from all commercial forest land, both public and private, was estimated to be \$1.34 per acre. It is probable that this figure is too low, both for public commercial forest in areas of relatively rapid tree growth and for private commercial forest in many areas of the United States. Although it was impossible to adjust the figures to take such variations into account in this report, further research will be undertaken to provide more realistic figures in the future.

Noncommercial forest. Valuation of "noncommercial" forest (the amount of forest remaining after the commercial forest is subtracted from total forest) is difficult. One approach would be to measure the increase in land value that could be attributed to the presence of a noncommercial forest adjacent to property that could be developed for either commercial or residential purposes. Another approach would be to measure the intangible values afforded society by a noncommercial forest, such as benefits of soil and water conservation and of recreation. Such values, if translated into tourist attractions and spending, appear

Table 4

ESTIMATED ACREAGES, TONNAGES AND VALUES OF PASTURE AND HAY IN COUNTIES
OF STATES WHERE POSSIBLE FLUORIDE CONTAMINATION EXISTS
1964

State	Pasture (Hay Equivalent)			Hay		
	Acres (000)	Tons (000)	Value (\$000)	Acres (000)	Tons	Value (\$)
Alabama	1,630	122.8	\$ 3,155.5	188	10,978	\$ 282,135
Arkansas	2,587	119.2	2,587.1	133	6,106	132,501
California	48,564	1,912.3	46,469.1	3,722	148,462	3,607,625
Colorado	19,030	233.8	6,452.2	139	2,315	63,894
Delaware	--	--	--	--	--	--
Florida	35,303	1,135.1	35,302.7	932	29,927	930,731
Idaho	3,214	155.8	3,147.7	330	16,062	324,452
Illinois	7,407	215.2	5,035.7	471	10,927	255,692
Indiana	2,331	100.9	2,331.9	136	0	0
Louisiana	1,952	52.1	1,188.2	152	4,999	113,978
Minnesota	1,686	21.4	488.7	146	2,764	63,019
Mississippi	2,717	23.2	514.8	275	0	0
Missouri	--	--	--	706	30,958	662,501
Montana	3,008	136.7	3,007.3	140	6,411	141,042
New Jersey	313	6.7	277.2	63	1,522	62,859
North Carolina	7,873	63.3	2,043.3	708	9,284	299,873
Ohio	2,282	91.3	2,282.6	119	4,763	119,075
Oklahoma	1,283	57.5	1,282.6	187	8,394	187,186
Oregon	7,176	279.3	7,177.1	570	22,177	569,949
South Carolina	705	13.5	434.5	66	1,629	52,291
Tennessee	7,561	190.7	4,986.3	567	13,313	350,132
Texas	48,023	654.7	16,105.7	2,271	68,218	1,678,163
Utah	6,178	286.6	6,178.2	90	4,163	89,920
Washington	13,880	603.5	13,880.2	1,943	84,537	1,944,351
West Virginia	1,802	41.9	1,420.2	107	2,604	88,276
Total	226,505	6,517.5	\$165,748.8	14,161	500,543	\$12,247,596

Table 5
NUMBER, AREA, AND POPULATION OF COUNTIES SURVEYED IN AIR POLLUTION STUDY
AS PERCENT OF TOTAL IN STATES

State	(a) No. of Counties in State	(b) No. of Counties Surveyed	(b) as Percent of (a)	Area Surveyed as Percent of State Total	Population of Area Surveyed as Percent of State Total	Combined Index of Area and Population
Alabama	67	11	16.4	21.1	28.1	25
Alaska	7	--	--	--	--	--
Arizona	14	8	57.1	50.9	88.5	70
Arkansas	75	9	12.0	11.6	26.0	19
California	58	22	37.9	48.2	87.6	68
Colorado	53	8	12.7	16.8	62.4	40
Connecticut	8	5	62.5	61.8	89.9	76
Delaware	3	2	66.6	69.9	85.3	77
District of Columbia	1	--	--	--	--	--
Florida	67	21	31.9	37.3	79.6	58
Georgia	159	12	7.5	7.2	40.5	24
Hawaii	5	1	20.0	9.3	79.1	45
Idaho	45	3	6.7	6.6	11.4	9
Illinois	102	28	27.4	31.1	77.0	54
Indiana	92	24	26.1	26.7	58.2	42
Iowa	99	9	9.1	10.4	30.1	20
Kansas	105	10	9.5	9.1	43.2	27
Kentucky	120	15	12.5	11.7	38.9	25
Louisiana	64	15	23.4	20.0	56.5	38
Maine	16	1	6.2	2.8	18.9	11
Maryland	24	8	33.3	35.6	52.4	44
Massachusetts	14	9	64.3	72.0	94.4	83
Michigan	83	14	16.7	18.3	63.9	41
Minnesota	87	9	10.3	17.2	53.5	35
Mississippi	82	6	7.3	9.5	22.6	16
Missouri	115	11	9.6	8.8	43.8	26
Montana	57	5	8.8	8.7	29.6	19
Nebraska	93	4	4.3	3.1	38.9	21
Nevada	17	3	17.6	21.0	77.7	49
New Hampshire	10	2	20.0	18.0	27.5	23
New Jersey	21	14	66.6	54.2	84.2	69
New Mexico	32	5	15.6	15.5	47.1	31
New York	62	22	35.5	35.0	41.2	38
North Carolina	100	18	18.0	21.7	31.4	26
North Dakota	53	1	1.9	3.0	2.2	3
Ohio	88	36	40.9	42.3	78.4	60
Oklahoma	77	11	14.3	14.7	48.8	32
Oregon	36	4	11.1	4.4	33.5	19
Pennsylvania	67	30	44.8	40.8	95.8	68
Rhode Island	5	4	80.0	89.1	90.5	90
South Carolina	46	9	19.6	25.9	28.2	27
South Dakota	67	--	--	--	--	--
Tennessee	95	13	13.7	15.8	52.4	39
Texas	254	51	20.1	17.7	65.3	41
Utah	29	5	17.2	14.3	64.9	39
Vermont	14	--	--	--	--	--
Virginia	98	12	9.2	9.7	21.9	16
Washington	39	12	30.8	31.4	72.3	51
West Virginia	55	15	27.3	24.9	43.5	34
Wisconsin	71	12	16.9	18.9	51.1	35
Wyoming	24	2	8.3	8.6	4.7	7
	3,085	551	17.9	16.0	61.2	39

to depend on the amount of development that has been achieved in order to attract tourists, as well as other factors. For instance, expenditures by tourists in 1968 in two large forested national parks in the State of Washington, for a limited set of services, were estimated at \$0.24 per acre in one case and \$4.08 per acre in the other.* For purposes of the present study, and pending further exploration of possible valuation methods, the annual value of noncommercial forest was arbitrarily set by SRI at one-half the value of commercial forest, or \$0.67 per acre.

Potential annual value of forest land. Table 6 shows the potential annual value of forest lands in pollution-threatened counties. Acreages, by states, of (1) federally owned or managed commercial forest land, (2) state, county, and municipal commercial forest land, and (3) private forest land were first estimated. These figures were totaled, giving the estimated commercial forest acreage, and then subtracted from total forest land⁷ to give the estimated noncommercial forest acreage for each state. By multiplying the commercial acreage by \$1.34 and the noncommercial acreage by \$0.67, a "potential sales" value was obtained. This is defined (for commercial acreage) as the annual sales value of forest products that could have been obtained if each acre had been exploited at its average capacity. For many acres, for various reasons, the forest was allowed to increase in value rather than to have enough forest products sold to equal the average sales value; in fact, this erratic harvesting is typical of the management of any specific plot of actual forest.

The next step was to calculate the acreage in the pollution-threatened counties as a percentage of the acreage in each state and to apply that percentage to both the state commercial and noncommercial acreages, as well as to the annual values, to obtain a first approximation of the value of forest products in those counties. The final step was to subtract from these gross figures the actual sales of forest products reported by the 1964 Census of Agriculture for the pollution-threatened counties (to avoid double-counting) to obtain the net potential value of sales.

* Adapted from William B. Beyers, "An Economic Impact Study of Mt. Ranier and Olympic National Parks," 1970. The values given are for Olympic and Mt. Rainier, respectively, and include only rentals (primarily boat), horseback rides, and guide and tour service.

Table 4

POTENTIAL ANNUAL VALUE OF FOREST LAND IN POLLUTION-THREATENED COUNTIES

State	Commercial Forest		Noncommercial Forest		Total Forest		Sales Reported (\$000)	Net Potential Value (\$000)
	Acres (000)	Potential Value (\$000)	Acres (000)	Potential Value (\$000)	Acres (000)	Potential Value (\$000)		
Alabama	4,109	\$ 5,506	3	\$ 2	4,112	\$ 5,508	\$ 862.2	\$ 4,645.8
Alaska	--	--	--	--	--	--	--	--
Arizona	1,964	2,629	8,130	5,446	10,094	8,075	4,042.2	4,032.8
Arkansas	2,604	3,490	9	8	2,613	3,498	334.5	3,163.5
California	8,748	11,653	12,652	8,436	21,400	20,079	924.3	19,154.7
Colorado	969	1,399	815	545	1,784	1,844	8.2	1,835.8
Connecticut	1,224	1,640	10	7	1,234	1,647	143.6	1,503.4
Delaware	273	367	1	1	274	368	58.4	309.6
District of Columbia	--	--	--	--	--	--	--	--
Florida	7,031	9,138	545	351	7,576	9,489	405.3	9,083.7
Georgia	2,157	2,678	4	2	2,161	2,678	265.8	2,412.2
Hawaii	101	136	83	56	184	192	0.0	192.0
Idaho	1,060	1,420	402	268	1,462	1,688	--	1,688.0
Illinois	1,206	1,459	33	24	1,239	1,483	149.8	1,339.2
Indiana	1,056	1,212	19	7	1,075	1,219	203.4	1,015.6
Iowa	271	362	0	0	271	362	20.5	341.5
Kansas	139	184	0	0	139	184	16.3	167.7
Kentucky	1,245	1,525	4	2	1,249	1,526	63.0	1,463.0
Louisiana	3,320	4,449	12	9	3,332	4,458	132.8	4,325.2
Maine	481	644	7	5	488	649	--	649.0
Maryland	1,040	1,199	9	6	1,049	1,205	142.5	1,062.5
Massachusetts	2,333	3,141	21	14	2,354	3,155	151.8	3,003.2
Michigan	3,499	4,430	108	66	3,607	4,496	418.8	4,077.2
Minnesota	3,222	4,320	377	252	3,599	4,572	418.2	4,153.8
Mississippi	1,670	2,288	4	2	1,674	2,288	186.0	2,102.0
Missouri	1,335	1,666	29	18	1,364	1,684	72.7	1,611.3
Montana	1,506	2,016	498	276	2,004	2,292	101.1	2,190.9
Nebraska	36	48	1	1	37	48	1.6	46.4
Nevada	23	30	2,505	1,677	2,528	1,707	0.5	1,706.5
New Hampshire	883	1,183	21	14	904	1,197	114.3	1,082.7
New Jersey	1,147	1,536	59	40	1,206	1,576	41.2	1,534.8
New Mexico	944	1,264	1,973	1,321	2,916	2,585	31.8	2,553.2
New York	4,656	5,821	952	595	5,608	6,416	957.9	5,458.1
North Carolina	4,307	5,446	138	87	4,445	5,533	886.7	4,646.3
North Dakota	13	17	0	0	13	17	6.8	10.2
Ohio	2,039	2,224	10	5	2,049	2,229	578.9	1,650.1
Oklahoma	678	809	502	301	1,180	1,110	22.6	1,087.4
Oregon	1,170	1,570	182	121	1,352	1,691	238.6	1,452.4
Pennsylvania	5,821	7,623	37	27	5,858	7,650	911.3	6,738.7
Rhode Island	429	516	4	3	433	519	12.3	506.7
South Carolina	2,955	3,967	21	14	2,976	3,981	380.1	3,600.9
South Dakota	--	--	--	--	--	--	--	--
Tennessee	2,210	3,061	41	29	2,251	3,090	210.0	2,880.0
Texas	2,076	1,888	2,076	944	4,152	2,832	277.3	2,554.7
Utah	572	766	1,567	1,050	2,139	1,816	--	1,816.0
Vermont	--	--	--	--	--	--	--	--
Virginia	1,661	2,227	72	45	1,733	2,272	355.0	1,917.0
Washington	6,125	8,209	1,112	745	7,237	8,954	915.5	8,038.5
West Virginia	2,827	3,783	19	15	2,846	3,798	301.1	3,596.9
Wisconsin	2,572	3,362	33	22	2,605	3,384	582.8	2,801.2
Wyoming	418	559	424	284	842	843	0.6	842.4
Total	96,125	\$124,760	35,523	\$23,133	131,648	\$147,897	\$15,848.3	\$132,038.7

Ornamental Plantings

Ornamentals were classified as to plantings:

- In various urban use areas (cemeteries, colleges, primary and secondary schools, industrial parks, and golf courses)
- On highway roadsides
- In parks
- Around private residences.

Calculation of the value of each category of ornamental planting in counties where potential damage to vegetation by air pollutants could occur involved the following principal steps:

1. Obtaining a basic estimate of the total acreage involved for the whole United States and for individual states.
2. Placing a dollar value on those acreages that indicated a total state-wide value as maintenance or replacement cost of such plantings.
3. Estimating the percentages of such dollar values represented by the counties in each state in which pollution damage was likely to occur.

It is difficult to find an acceptable value for ornamentals in public and private areas that do not have a market value based on an annual harvest. As a minimum estimate of the value placed on such ornamentals, SRI has placed the value of the annualized cost of establishing and maintaining such plantings on a permanent basis, or, alternatively, the cost of replacement of such ornamentals if they were to be eliminated. It is argued that society (in the case of publicly owned property) or the individual (in the case of privately owned property) expends the price of establishing, maintaining, or replacing the ornamentals and thus values them by at least the amount spent. Such a method of evaluation also has the merit that certain types of data are available with which to make the estimate and that researchers can usually agree on the methods used in such evaluations.

The dollar value of each category of ornamental plantings for each state was obtained by the methods described below for each category.

Ornamentals on various urban lands. The ornamental plantings considered here are those found in cemeteries, industrial parks, colleges, primary and secondary schools, and golf courses. Although these land uses vary greatly, it was possible to use similar methodologies in many cases to make the necessary estimates. The estimates for the various

uses defined above are shown in Table 7. State acreages and costs were allocated to pollution-threatened counties according to population.

Cemeteries. Published information on cemeteries is very fragmentary. Limited statistics from turf grass surveys* were supplemented by telephone interviews with selected cemetery associations, state and local government officials, and cemetery directors. Over 200,000 acres were estimated by SRI to be in cemeteries in the United States, and an estimated twenty percent† of this acreage was placed in trees and ornamentals. The acreage was allocated according to population.

Colleges. An SRI survey estimated somewhat over 200,000 acres in college campuses, with 50%† of this acreage being devoted to grass and shrubbery and 10% being planted in trees and ornamentals.‡ The acreage was allocated according to population.

Secondary schools. An SRI survey was used to supplement published data; over 180,000 acres were estimated to be devoted to grass and shrubbery, and 20% of this was the estimate for trees and ornamentals.† This acreage was allocated according to population.

Primary schools. Sources of published data for schools were supplemented by a telephone interview with school architects. It was estimated that 230,000 acres were devoted to grass and shrubbery, and 20% of this was the estimate for trees and ornamentals.† This acreage was allocated according to population.

Industrial parks. Published information was supplemented by an SRI survey.‡ Of an estimated 280,000 acres in such parks, 30 percent was estimated to be in grass and shrubbery and 6 percent in trees and ornamentals.†

Golf courses. An SRI survey was utilized, which included information from the National Golf Foundation. Of an estimated 835,000 acres in golf courses, 10 percent was estimated to be planted in trees and shrubbery.† This acreage was allocated according to population.

* Such as the "Washington Turfgrass Survey, 1967," done by the State of Washington. Total area in grass and ornamentals in cemeteries in the state was found to be 4400 acres.

† These estimates are subject to correction if improved data show them to be incorrect.

‡ See also articles on campus planning in Urban Land for December 1966.

§ See also: "Site Selection Issue" in Industrial Development and Management Record, June 1969.

Table 7

ESTIMATED ACREAGES AND ANNUAL COSTS TO POLLUTION-THREATENED COUNTIES
FOR MAINTENANCE OF TREES AND SHRUBS IN VARIOUS URBAN LAND USES
1964

State	State (thousands of acres)							Pollution- Threatened Counties	
	Cemeteries	Colleges	Secondary Schools	Primary Schools	Industrial Parks	Golf Courses	Total	Acres (000)	Cost of Maintenance ^a (\$000)
Alabama	0.7	0.4	0.7	0.8	0.3	1.5	4.4	1.5	\$ 6,592
Alaska	--	--	--	--	--	--	--	--	--
Arizona	0.3	0.2	0.3	0.4	0.1	0.7	2.0	1.2	5,392
Arkansas	0.4	0.2	0.4	0.5	0.2	0.8	2.5	0.4	1,794
California	3.8	2.1	3.5	4.3	1.6	7.9	23.2	13.7	61,583
Colorado	0.4	0.2	0.4	0.5	0.2	0.8	2.5	1.1	5,109
Connecticut	0.6	0.3	0.5	0.6	0.2	1.2	3.4	2.1	9,249
Delaware	0.1	0.1	0.1	0.1	b	0.3	0.7	0.4	1,789
District of Columbia	--	--	--	--	--	--	--	--	--
Florida	1.2	0.7	1.1	1.4	0.5	2.5	7.4	3.9	17,648
Georgia	0.9	0.5	0.8	1.0	0.4	1.8	5.4	1.0	4,581
Hawaii	0.2	0.1	0.2	0.2	0.1	0.3	1.1	0.5	2,689
Idaho	--	--	--	--	--	--	--	0.1	1,574
Illinois	2.2	1.2	2.0	2.5	0.9	4.6	13.4	7.4	32,598
Indiana	1.0	0.6	0.9	1.2	0.4	2.1	6.2	2.4	10,826
Iowa	0.6	0.3	0.5	0.6	0.2	1.2	3.4	0.7	3,000
Kansas	0.5	0.2	0.4	0.6	0.2	1.0	2.9	0.9	3,733
Kentucky	0.7	0.4	0.6	0.8	0.3	1.4	4.2	1.1	4,711
Louisiana	0.7	0.4	0.7	0.8	0.3	1.5	4.4	1.6	7,517
Maine	--	--	--	--	--	--	--	0.2	900
Maryland	0.7	0.4	0.7	0.8	0.3	1.5	4.4	2.4	10,981
Massachusetts	1.1	0.6	1.0	1.3	0.5	2.3	6.8	4.4	19,488
Michigan	1.7	1.0	1.6	2.0	0.7	3.6	10.6	4.5	20,233
Minnesota	0.7	0.4	0.7	0.8	0.3	1.5	4.4	1.8	8,062
Mississippi	0.5	0.2	0.4	0.6	0.2	1.0	2.9	0.4	1,931
Missouri	0.9	0.5	0.8	1.1	0.4	1.9	5.6	1.6	7,412
Montana	0.2	0.1	0.2	0.2	0.1	0.3	1.1	0.2	879
Nebraska	0.3	0.2	0.3	0.4	0.1	0.7	2.0	0.5	2,412
Nevada	0.1	b	0.1	0.1	b	0.2	0.5	0.3	1,169
New Hampshire	0.1	0.1	0.1	0.1	b	0.3	0.7	0.1	605
New Jersey	1.4	0.8	1.3	1.6	0.6	2.9	8.6	4.7	21,049
New Mexico	0.2	0.1	0.2	0.2	0.1	0.4	1.2	0.4	1,976
New York	3.8	2.1	3.5	4.3	1.6	7.9	23.2	6.5	26,914
North Carolina	1.0	0.6	0.9	1.2	0.4	2.1	6.2	1.3	5,827
North Dakota	--	--	--	--	--	--	--	--	--
Ohio	2.1	1.2	1.9	2.4	0.9	4.4	12.9	6.7	29,720
Oklahoma	0.5	0.3	0.5	0.6	0.2	1.1	3.2	1.0	4,733
Oregon	0.4	0.2	0.4	0.5	0.2	0.8	2.5	0.9	3,751
Pennsylvania	2.4	1.2	2.2	2.7	1.0	5.0	14.5	8.0	35,590
Rhode Island	0.2	0.1	0.2	0.2	0.1	0.4	1.2	0.7	3,154
South Carolina	0.5	0.3	0.5	0.6	0.2	1.1	3.2	0.7	3,362
South Dakota	--	--	--	--	--	--	--	--	--
Tennessee	0.8	0.4	0.7	0.9	0.3	1.7	4.8	1.7	7,602
Texas	2.2	1.2	2.0	2.5	0.9	4.5	13.3	5.9	26,143
Utah	0.2	0.1	0.2	0.2	0.1	0.4	1.2	0.5	2,361
Vermont	--	--	--	--	--	--	--	--	--
Virginia	0.9	0.5	0.8	1.0	0.4	1.9	5.5	1.3	5,790
Washington	0.6	0.4	0.6	0.7	0.3	1.3	3.9	2.0	8,885
West Virginia	0.4	0.2	0.4	0.5	0.2	0.8	2.5	1.2	3,125
Wisconsin	0.8	0.5	0.8	1.0	0.4	1.8	5.3	1.8	8,112
Wyoming	0.1	b	0.1	0.1	b	0.2	0.5	b	--
Total								101.7	\$451,671

a. Estimated, based on figures obtained in survey for ornamentals planted along highways and in roadside parks.
b. Less than 500 acres.

Highway roadsides. Estimated roadside landscaping acreage and costs are given in Table 8. The general basis for the assumptions used in estimating these acreages and costs was derived from a series of telephone interviews conducted with landscape architects and highway horticulturalists in various parts of the United States.* The basic highway mileage data was provided in "Highway Statistics, 1964" published by the U.S. Bureau of Public Roads. Acreage of highway ornamental landscaping was allocated to counties according to the "combined area-population" index. Valuation of highway ornamental acreage was based on a number of cost factors, including routine operation and maintenance costs as well as a proportion of shrubbery replacement costs, and varied from a very nominal figure up to \$750 per acre per annum.† The series of assumptions developed by SRI to estimate roadside acreages of shrubs and trees are given below. Simplifying averages had to be used, in spite of the fact that variations exist for each factor.

1. State differentiation. Assume state differentiations due to "dry" and "humid" weather. "Dry" states include Arizona, California, Nevada, New Mexico, Texas, Idaho, and Utah. In these states, assume that there is little effort to maintain turf grass on rural roadsides and that rural road landscaping is primarily composed of shrubs and trees. Assume that all urban road landscaping includes permanent irrigation equipment. States that are part humid and part dry, such as Washington and Oregon, or part mountain and part plains, such as Colorado, were assigned simplifying assumptions that apply state-wide.
2. Rest areas. Assume that rest areas exist only in rural areas and are located one-half hour's driving time apart (35 miles). Rest areas now exist on interstate highways and to varying extents on other primary highways.
3. Interchanges: urban. Assume that urban interchanges are an average five miles apart and are located only on streets with access control.

* Names in the selected states were obtained from two source books: (1) American Association of State Highway Officials, Reference Book of Member Department Personnel and Committees, 1970; (2) American Road Builders' Association, Highway Officials and Engineers, "Directory of Personnel," June 1968.

† A very brief listing of reports and articles found useful in providing background includes: (1) Automotive Safety Foundation, Development and Management of Mississippi's State Highways: 1960-1980; (2) Michigan Highway Department, Michigan's Highways: 1960-1980; (3) U.S. Bureau of Public Roads, Highways and Economic and Social Changes, 1964; (4) SRI, Impact of Improved Highways on the Economy of the United States, prepared for the U.S. Bureau of Public Roads, 1958.

Table 8
ESTIMATED ANNUAL COSTS TO POLLUTION-THREATENED COUNTIES FOR ROADSIDE LANDSCAPING^a
1984

State	County Costs (thousands of dollars)			Total
	Rural Primary	Urban Primary	Urban-Rural Secondary	
Alabama	\$ 111	\$ 128	\$ 187	\$ 426
Alaska	--	--	--	--
Arizona	414	214	--	628
Arkansas	23	31	143	197
California	1,503	7,183	--	8,686
Colorado	112	154	35	301
Connecticut	112	218	22	352
Delaware	24	45	26	95
District of Columbia	--	--	--	--
Florida	19	176	173	368
Georgia	74	132	79	285
Hawaii	12	13	6	31
Idaho	--	--	--	--
Illinois	364	634	176	1,174
Indiana	147	110	174	431
Iowa	100	113	148	361
Kansas	103	129	136	368
Kentucky	58	76	82	216
Louisiana	62	94	73	229
Maine	--	--	--	--
Maryland	80	213	99	392
Massachusetts	134	341	41	516
Michigan	218	246	237	701
Minnesota	163	337	266	766
Mississippi	52	86	59	197
Missouri	147	195	147	489
Montana	67	19	29	115
Nebraska	63	43	82	188
Nevada	338	18	--	356
New Hampshire	99	25	9	133
New Jersey	257	247	32	536
New Mexico	221	138	--	359
New York	252	689	171	1,112
North Carolina	77	84	171	332
North Dakota	--	--	--	--
Ohio	263	472	247	982
Oklahoma	134	789	89	1,012
Oregon	73	51	50	174
Pennsylvania	288	590	180	1,058
Rhode Island	23	26	10	59
South Carolina	88	62	127	277
South Dakota	--	--	--	--
Tennessee	127	77	89	293
Texas	1,137	4,579	--	5,716
Utah	141	194	--	335
Vermont	--	--	--	--
Virginia	79	81	96	256
Washington	137	153	140	430
West Virginia	62	81	117	260
Wisconsin	128	110	145	383
Wyoming	17	2	4	23
Total	\$6,103	\$18,748	\$4,097	\$30,948

a. Trees and shrubs only.

Interchanges: rural. Assume that rural interchanges are an average ten miles apart on all highways with access control and on half the highway mileage of other four-lane and divided highways.

4. Landscaping. Assume landscaping on highway mileage in a range from 0 percent to 100 percent, depending on type of highway* and location of state. For each mile of landscaped highway, assume one to five acres of trees and shrubs, depending on location and type of highway. For eligible highway interchanges, assume 2.5 to 12.5 acres of trees and shrubs, depending on whether the interchange is urban or rural and its location within the United States. For rest areas, assume 3 to 7.5 acres of trees and shrubs.

City, county, state, and national parks. The data given in Table 9 were obtained from several official sources.⁸ The park acreage devoted to trees and shrubs was estimated at 50%.[†] Estimated annual costs of repair, upkeep and maintenance were obtained from the same published sources; reported costs of personnel salaries and wages were added to costs for current operating expenditures. Acreages and costs were allocated based on area.

As with forests, it is difficult to estimate the value of parks to the U.S. public in any meaningful quantitative terms.[‡] When a park area is acquired or established, considerable capital investment is required to prepare it for use by the public--the building of new roads, buildings, camping and housing facilities, etc. Once this capital investment is made, annual expenditures can shift to a maintenance basis (although in practice, capital improvements in a park may continue for many years). Much of the annual cost of park maintenance can be directly related to upkeep of its trees and shrubs--watering, fertilizing, weeding, trimming and removing, planting, spraying, fire control, and numerous other tasks. A major part of this cost is the cost of personnel required for these tasks. Consequently, even though other types of personnel and their associated costs[§] are included in the totals reported, it was decided

* Urban or rural; full, limited, or free access; divided, 4-lane, or 2-lane primary; secondary.

† This would vary, depending on the location of the park and other factors. Modification of this estimate will be attempted in further research.

‡ A publication of the National Park Service, "The Economics of Public Recreation: An Economic Study of the Monetary Evaluation of Recreation in the National Parks," concludes: "...it was impossible to measure the economic benefits of the National Park system in dollars and cents on any basis other than judgment." (Washington, D.C., 1949)

§ Office personnel and park rangers, road repair and building maintenance, etc.

Table 9

ESTIMATED ACREAGES AND ANNUAL COSTS TO STATES AND POLLUTION-THREATENED COUNTIES
FOR MAINTENANCE OF TREES AND SHRUBS IN CITY, COUNTY, STATE, AND NATIONAL PARKS
1964

State	State		Pollution-Threatened Counties	
	Acres (000)	Cost (\$000)	Acres (000)	Cost (\$000)
Alabama	196	\$ 3,512	41	\$ 741
Alaska	--	--	--	--
Arizona	1,521	9,892	774	5,035
Arkansas	47	534	5	62
California	2,613	111,135	1,259	33,367
Colorado	318	5,452	54	992
Connecticut	84	8,736	52	5,399
Delaware	9	1,278	6	893
District of Columbia	--	--	--	--
Florida	1,958	21,918	730	8,175
Georgia	130	5,442	9	392
Hawaii	743	4,595	69	427
Idaho	--	--	--	--
Illinois	90	52,112	28	16,248
Indiana	117	9,112	31	2,433
Iowa	63	6,018	7	626
Kansas	40	3,666	3	284
Kentucky	106	6,306	12	738
Louisiana	6,784	3,396	1,250	620
Maine	--	--	--	--
Maryland	104	11,127	37	3,981
Massachusetts	170	10,020	110	6,480
Michigan	2,293	31,890	362	5,023
Minnesota	904	10,426	155	1,793
Mississippi	137	1,679	12	143
Missouri	167	13,438	14	1,032
Montana	885	2,246	77	195
Nebraska	40	3,703	1	115
Nevada	490	2,484	103	522
New Hampshire	38	2,187	7	394
New Jersey	142	15,510	77	8,406
New Mexico	268	2,282	42	354
New York	1,742	77,895	610	27,263
North Carolina	395	7,102	63	1,509
North Dakota	--	--	--	--
Ohio	256	23,880	108	10,101
Oklahoma	234	4,488	34	660
Oregon	587	8,416	26	370
Pennsylvania	1,509	27,145	675	12,137
Rhode Island	13	1,590	12	1,417
South Carolina	75	2,498	19	617
South Dakota	--	--	--	--
Tennessee	479	8,756	84	1,528
Texas	525	19,676	91	3,443
Utah	824	3,881	118	555
Vermont	--	--	--	--
Virginia	218	8,026	21	779
Washington	2,628	9,348	825	2,935
West Virginia	132	2,532	31	602
Wisconsin	331	23,258	72	5,005
Wyoming	1,218	4,063	105	351
Total	31,277	\$593,070	8,221	\$194,330

to use the current personnel and operating costs as a first approximation of the costs of maintaining park shrubbery in its present condition, and to accept this cost, now borne by the public, as a public evaluation of the worth of trees and ornamentals grown in parks. It was also decided that any new plantings placed in parks would usually be acquired outside the normal commercial channels.

Land occupied by private residences. SRI held a number of telephone interviews with various city planning departments, in addition to obtaining information from published sources.* In the pollution-threatened counties, the number of residences was calculated based on population. Residence location was designated as "central city," "urban," or "rural." Different proportions of single-family, 2- to 4-family, and multiple-family residences were assumed in each of the three levels of urbanization. In each case, 20 percent of the open space around the residence was assumed to be devoted to trees and ornamentals. In only one type of housing situation--the multiple-family dwelling in the central city--was it assumed that there was virtually no landscaping. The 1960 and 1964 censuses of population and housing were used to estimate size of family and the percentage distribution of the different types of housing. Estimated acreage planted to trees and ornamentals was multiplied by an annual maintenance cost of \$750 per acre to obtain annual cost figures.† The results of the various calculations are shown in Table 10. Allocation of acreage and costs to pollution-threatened counties was made on the basis of population.

Sensitivity of Various Plant Species to the Specific Pollutants

To arrive at a more realistic method of assigning losses to crops and ornamentals based on their differing sensitivities to various pollutants, the literature has been continuously reviewed and a table was prepared indicating the relative sensitivity of the plants on which such information was available. The results of this survey are shown in Table 11, in which some 200 different species are listed by the type of crop.

* A brief list of useful reports and articles would include: (1) Urban Land Institute bulletins No. 42 and 420, 1961; (2) articles in Urban Land for July-Aug. 1955, May 1960, Oct. 1961, Oct. 1963, Oct. 1964, April and Oct. 1967; (3) San Francisco Housing Stock Census, 1970; (4) HUD Federal Housing Administration, Minimum Standards for Low Cost Housing.

† This figure for an acre of trees and ornamentals would be divided among a number of families, so that the figure per family per residence would be much lower than \$750.

Table 10
ESTIMATED ACREAGES IN AND ANNUAL COSTS TO POLLUTION-THREATENED COUNTIES
FOR MAINTENANCE OF TREES AND ORNAMENTALS AROUND PRIVATE RESIDENCES

State	Acres (000)				Costs (\$000)
	Central City	Other Urban	Rural	Total	
Alabama	1.3	3.3			
Alaska	--	--	21.3	25.9	\$ 19,381
Arizona	0.7	1.4	--	--	--
Arkansas	0.2	0.5	6.1	8.2	6,067
California	7.5	31.1	5.3	6.0	4,501
Colorado			24.7	63.3	47,412
Connecticut	0.3	3.7			
Delaware	0.6	4.3	1.6	5.6	4,163
District of Columbia	--	1.3	8.7	13.6	10,263
Florida	--	--	2.4	3.7	2,772
	0.5	13.5	--	--	--
Georgia			20.7	34.7	26,044
Hawaii	--	3.1			
Idaho	0.2	1.0	5.3	8.4	6,192
Illinois	0.1	0.8	1.0	2.2	1,650
Indiana	2.8	24.5	1.3	2.2 ^a	1,574
	0.6	7.6	22.6	49.9	37,636
Iowa			17.2	25.4	18,896
Kansas	0.1	2.5			
Kentucky	0.3	2.3	5.0	7.6	5,566
Louisiana	0.3	3.2	4.0	6.6	4,817
Maine	0.5	4.5	6.8	10.3	4,303
	0.1	1.0	8.5	13.5	10,329
Maryland			1.5	2.6 ^a	1,976
Massachusetts	1.0	11.3			
Michigan	1.7	13.1	14.0	26.3	19,530
Minnesota	1.7	13.2	11.8	26.6	19,892
Mississippi	0.7	5.5	15.0	29.9	22,420
	0.1	1.1	6.0	12.2	9,039
Missouri			3.4	4.6	3,550
Montana	1.0	8.2			
Nebraska	--	2.1	4.8	14.0	10,336
Nevada	0.3	1.2	4.3	6.4	1,559
New Hampshire	--	0.9	1.3	2.8	2,101
	--	0.4	0.7	1.6	1,203
New Jersey			2.5	2.9	2,175
New Mexico	1.5	16.2			
New York	0.1	1.1	6.1	25.8	19,332
North Carolina	1.2	22.0	2.4	3.6	2,469
North Dakota	0.1	2.5	33.0	56.2	41,998
	--	0.3	19.4	22.0	16,583
Ohio			0.4	0.7 ^a	543
Oklahoma	2.2	20.0			
Oregon	0.6	3.1	35.0	57.2	43,163
Pennsylvania	0.3	2.5	4.5	8.2	6,111
Rhode Island	2.0	27.2	1.7	4.5	3,389
	0.2	2.2	49.8	79.0	59,415
South Carolina			1.8	4.2	3,195
South Dakota	b	1.4			
Tennessee	--	--	11.8	13.2	9,879
Texas	--	--	--	--	--
Utah	2.0	4.2	10.7	14.9	11,511
	0.1	17.1	19.3	38.4	28,901
Vermont		1.6	1.4	3.1	2,360
Virginia	--	--	--	--	--
Washington	0.6	6.1	14.0	20.7	15,594
West Virginia	0.5	5.9	13.2	19.6	14,779
Wisconsin	b	3.2	16.6	19.8	8,805
	0.6	5.5	8.0	14.1	10,549
Wyoming	--	--	--	--	--
Total	34.6	308.7	479.3	822.6	\$604,223

a. Urban/rural distribution for these counties based on total distribution.
b. Less than 100 acres.

Table 11

ESTIMATES OF RESISTANCE AND SENSITIVITY OF
VARIOUS CROPS TO DIFFERENT POLLUTANTS
S = Susceptible, I = Intermediate, R = Resistant

	Pollutant and Sensitivity					
	Ozone	Nitrogen Dioxide	PAN	General Oxidant	Sulfur Dioxide	Hydrogen Fluoride
<u>Field crops</u>						
Alfalfa	S		I	S	S	R
Barley	S		I		S	I
Beans (field)	S	S	S	S	S	R
Buckwheat					S	S
Clover (hay)	S			S	S	R
Corn (field)		R			R	I
Cotton					S	R
Lespedeza						
Oats	S		S	S	S	I
Peanuts	S					
Potatoes (Irish)	S				R	R
Rye	S	I			S	
Safflower					S	
Sorghum			R			I
Soybean			I		S	R
Sugar beets			I	S	I	R
Sunflower		S			S	I
Tobacco	S	S	I	S		R
Wheat	S		I		S	R
<u>Seed crops</u>						
Alfalfa	S		I	S	S	R
Clover	S		I	S	S	R
Alsike					S	
Crimson					S	
Ladino					S	
Red					S	
Lespedeza						
Mustard		S			I	

Table 11 (continued)

	Pollutant and Sensitivity					
	<u>Ozone</u>	<u>Nitrogen Dioxide</u>	<u>PAN</u>	<u>General Oxidant</u>	<u>Sulfur Dioxide</u>	<u>Hydrogen Fluoride</u>
<u>Citrus</u>				S	R	I
Grapefruit						I
Kumquats						
Lemons						I
Limes						
Oranges		I				
Valencia						
Navel						
Temple						
Mandarins						
Tangerines						I
Tangelos						
<u>Fruits and nuts</u>						
Almonds						
Apples					S	
Apricots					I	S
Avocados						
Blackberries						
Blueberries						S
Cherries						R
Sour					R	
Sweet						
Grapes	S			S	I	S
Peaches					I	
Clingstone						
Freestone						S
Pears					S	R
Pecans						
Plums					I	S
Prunes						S
Strawberries						R
Walnuts						I
Raspberry						I
Figs						I

Table 11 (continued)

	Pollutant and Sensitivity					
	Ozone	Nitrogen Dioxide	PAN	General Oxidant	Sulfur Dioxide	Hydrogen Fluoride
<u>Vegetables</u>						
Asparagus		R			R	R
Beans, snap		S	S		S	R
Beans, lima		S	R		S	I
Beets (table)	S		I	S	S	R
Broccoli			R		S	
Brussel sprouts					I	
Cabbage			I		S	
Carrots					I	
Cauliflower				I	R	R
Celery			R		R	S
Corn (sweet)	S		R		R	
Cucumber				S	S	
Endive and escarole					I	
Eggplant					S	R
Lettuce (head)		S		S	R	
Muskmelon	S				S	
Okra					R	
Onion	S		R		I	
Parsley					I	
Parsnip					I	
Peas					I	
Peppers					S	
Potato (sweet)					S	
Pumpkin			R	I		
Radish	S		S	S		
Romaine			I	S	S	
Spinach	S				S	
Squash			S		S	
Swiss chard			S		I	R
Tomatoes	S	S			S	
Turnip						

Table 11 (continued)

	Pollutant and Sensitivity					
	Ozone	Nitrogen Dioxide	PAN	General Oxidant	Sulfur Dioxide	Hydrogen Fluoride
<u>Flowering plants</u>						
Aster					I	I
Azalea		S	R			
Bachelor's button					S	
Begonia			R		I	
Canna					R	
Carissa		R				
Carnation	S					
Chrysanthemum	S		R		R	
Cosmos					S	
Croton		R				
Dahlia		R				
Four o'clock					R	
Geranium						I
Gladiolus					R	S
Goldenrod						I
Heath		R				
Hibiscus		S			R	
Hollyhock					I	
Honeysuckle					R	
Hydrangea					I	
Iris					I	
Ixora		R				
Lilac	S					I
Marigold					I	
Morning glory					S	
Narcissus						I
Nasturtium					I	
Peony						I
Periwinkle			R			
Petunia	S		S	S		
Privet	S					
Pyrocantha						R

Table 11 (continued)

	Pollutant and Sensitivity					
	Ozone	Nitrogen Dioxide	PAN	General Oxidant	Sulfur Dioxide	Hydrogen Fluoride
<u>Flowering plants (cont.)</u>						
Rhododendron						I
Rose					R	I
Snowball					R	
Snowberry	S					
Spired	S					R
Sunflower		S			I	I
Sweet pea					S	
Sweet william					I	
Touch-me-not			R			
Tulip						S
Verbena					S	
Violet				S	S	I
Virginia creeper					R	R
Wisteria					R	
Zinnia					S	
<u>Trees and native shrubs</u>						
Alder	S					
Arbor-vitae					R	I
Ash (green)						I
Aspen (quaking)	S					I
Birch					S-I	R
Box elder	S				R	S
Brittlewood		S				
Catalpa	S				S-I	
Douglas fir						S
Elderberry						R
Elm (American)					S-I	R
Honeylocust	S					
Juniper (most species)					R	R
Larch					S	S
Linden, American					I	R
Linden, European						I

Table 11 (continued)

	Pollutant and Sensitivity				
	<u>Ozone</u>	<u>Nitrogen Dioxide</u>	<u>PAN</u>	<u>General Sulfur Oxidant</u>	<u>Dioxide Hydrogen Fluoride</u>
<u>Trees and native shrubs (cont.)</u>					
Maple					
Silver	S			R	I
Sugar					R
Hedge					I
Mock orange				R	
Mulberry				S	
Oak, Gambel	S				
Oak, live				R	
Oregon grape					S
Pine					
Eastern, white	S		S	S	S
Lodgepole					S
Mugho					S
Scotch					S
Western, yellow	S		S	S	S
Poplar, Carolina					I
Poplar, Lombardy				S-I	I
Service berry					I
Spruce, blue					S
Spruce, white					I
Sumac					I
Sycamore	S				R
Tobacco tree				S	
Tree of Heaven					R
Walnut, black					I
Walnut, English					I
Willow, weeping	S				R
Yew				S	I

Table 11 (concluded)

	Pollutant and Sensitivity					
	Ozone	Nitrogen Dioxide	PAN	General Oxidant	Sulfur Dioxide	Hydrogen Fluoride
<u>Weeds and grasses</u>						
Bindweed					S	
Careless weed					S	
Cheeseweed		I	I	S	S	R
Chickweed		I	S		R	I
Cocklebur					I	
Dock sour					S	
Fleabane					S	
Goosefoot nettle (leafed)		R		I	R	S
<u>Grasses</u>						
Annual blue			S	S	R	R
Bent	S					
Brome	S					
Crab	S					
June					S	
Kentucky blue		R			R	R
Orchard	S				I	R
Rye					S	
Salt					R	
Lambsquarters			I		I	I
Milkweed					R	
Mustard, black			S		I	
Mustard, yellow						
Nettle (little leaf)			S			
Nightshade					I	
Pigweed		R				
Plantain					S	
Purslane					R	
Ragweed					S	
Shepherd's purse					R	
Smartweed					I	
Sweet clover					I	

The data for Table 11 were assembled from many sources, but primarily the following:

1. Recognition of Air Pollution Injury to Vegetation: A Pictorial Atlas. Informative Report No. 1. TR7 Committee, Air Pollution Control Association, Pittsburgh, Pa., 1970. Edited by J. S. Jacobson and A. Clyde Hill.
2. Farbtafelatlus uber Schwefeldioxid-Werkungen an Pflangen. H. Van Hout and H. Stratmann. W. Gerardet, Essen, 1970.
3. Air Pollution Injury to Vegetation. I. W. Hindawi. National Air Pollution Control Office Publication No. AP-71. Raleigh, North Carolina, 1970.

As mentioned in the Introduction, the dollar loss estimates given in the first annual report were calculated by assuming that all the sensitive species suffered equally as a result of an air pollution episode (a recognized fallacy). During this report period, an attempt was made to develop relative damage percentages for various crops as a result of a pollution episode of a specific concentration.

Every year the California State Department of Agriculture, through its Los Angeles office, publishes estimates of percentage loss as well as total dollar loss to crops as a result of smog. Since 1969, the Center for Air Environment Studies of Pennsylvania State University has been estimating dollar losses to air pollutants in various counties in Pennsylvania. From these publications⁹⁻¹³ and published and unpublished data from other sources, percentage losses to various crops that could occur in counties suffering from the most severe pollution were obtained. Using this information, plus the data in Table 11 showing comparable sensitivity of various crops to the various pollutants, Table 12 was prepared showing estimated percentages of crop losses that might occur in counties with the heaviest pollution. There are still many crops on which information as to sensitivity is not available.

Formulae for Calculating Dollar Loss

In the previous year, the following formula was developed to express the dollar loss of a particular crop due to a particular pollutant:

$$C = P^D Q^D \left(\frac{Q^C - Q^D}{Q^C} \right)$$

where C = approximate dollar loss

P^D = price per unit produced under polluted conditions

Q^D = number of units produced under polluted conditions

Q^C = potential units produced under clear air conditions.

Table 12

ESTIMATED PERCENTAGES OF CROPS LOST IN COUNTIES MOST POLLUTED BY
OZONE, PAN, AND OXIDES OF NITROGEN; SULFUR DIOXIDE; AND HYDROGEN FLUORIDE
(Species Are Grouped According to Listing in Table 11)

Crop	Percentage of Crop Lost		
	Ozone, PAN, Oxides of Nitrogen	Sulfur Dioxide	Hydrogen Fluoride
<u>Field crops</u>			
Alfalfa	30	10	10
Barley	5	5	
Beans	5	5	
Buckwheat		10	
Clover	30	10	10
Corn field	5		10
Cotton	2	5	
Lespedeza			10
Oats	5	5	
Peanuts	5		
Potatoes, Irish			
Rye	5	5	
Safflower		5	
Sorghum	2		
Soybean	5	5	
Sugar beet	10	2	
Sunflower	5	5	
Tobacco	10		
Wheat	5	5	
<u>Seed crops</u>			
Alfalfa	10	10	
Clover	10		
Alsike		10	
Crimson		10	
Ladino		10	
Red		10	
Lespedeza			
Mustard	10	5	

Table 12 (continued)

Crop	Percentage of Crop Lost		
	Ozone, PAN, Oxides of Nitrogen	Sulfur Dioxide	Hydrogen Fluoride
<u>Citrus</u>	30	1	5
Grapefruit			5
Lemons	30		5
Oranges			5
<u>Fruits and nuts</u>			
Almonds			
Apples		5	
Apricots		2	5
Avocados	5		
Blueberries			5
Cherries		1	1
Figs	10		
Grapes	20	2	5
Peaches		2	3
Pears		5	1
Pecans			1
Plums		2	5
Prunes			5
Strawberries			1
Walnuts		1	2
Raspberries			2
<u>Vegetables</u>			
Asparagus	1	1	1
Beans, snap	10	5	1
Beans, lima	5	5	1
Beets	10	5	1
Broccoli	5	5	
Brussel sprouts	1	5	
Cabbage	5	1	
Carrots	2	5	
Cauliflower	5	2	
Celery	10	1	1
Corn, sweet	2	1	5
Cucumber	5	2	
Endive	10	5	
Eggplant		2	

Table 12 (concluded)

Crop	Percentage of Crop Lost		
	Ozone, PAN, Oxides of Nitrogen	Sulfur Dioxide	Hydrogen Fluoride
<u>Vegetables (cont.)</u>			
Lettuce (leaf)	10		
Lettuce (head)	2	5	1
Muskmelon	5	1	
Okra		5	
Onion	2	1	
Parsley	5	2	
Parsnip		2	
Peas		2	
Peppers	5	2	
Potato, sweet		5	
Pumpkin	5	5	
Radish	5	2	
Romaine	10	1	
Spinach	10	1	
Squash		5	
Swiss chard	5	5	
Tomatoes	2	2	
Turnips	5	5	
<u>Nursery stock^a</u>			
General	5	2	1
<u>Trees and native shrubs^a</u>			
General	2	2	1
<u>Weeds and grasses^a</u>			
Lawn grasses	2		
General ^b			

- a. So many species are involved in this category and so little is known about the sensitivity and resistance of individual species that a general value has been given for the groups as a whole based on average estimates of Los Angeles County for ozone, PAN, and oxides of nitrogen, and general observations and experience for sulfur dioxide and hydrogen fluoride.
- b. Effect on weeds may be an ecological loss but not an economic one.

This essentially says that the current value of a crop under smog conditions times the fractional yield reduction is a fair approximation of the crop loss in dollars due to the particular air pollutant.

The difficulty in applying the above formula is, of course, in estimating the yield reduction ascribable to air pollutants. As indicated in Table 12, no quantitative data are available on the effects of air pollutants on yield or growth for some crops. Crops vary greatly in their response to pollutants, depending on species and environmental conditions. Not only do crops vary in their response to different pollutants, but (as indicated in Table 2) the relative severity of the pollution varies from county to county, depending on the emissions, meteorological conditions, and topography. In spite of all these difficulties, a systematic formula was applied to each county for each pollutant and for each crop, forest, and ornamental planting as follows.

First, the counties in which plant-damaging pollution was likely to occur were placed in classes of different relative pollution intensities for each pollutant, i.e., oxidants (ozone, PAN, and oxides of nitrogen), sulfur dioxide, and fluorides. According to the 1962 City and County Data Book,⁴ there were 3,134 counties in the United States (as of December 1965, this number had declined to 3,109). The classes in which the counties were placed are given below in increasing order of severity of pollution.

The classes for oxidant pollution, along with the number of counties in each class, are:

- Class 0: The 2,807 counties not included in the Standard Metropolitan Statistical Areas.
- Class 1: The 141 counties in an SMSA but not in the 65 SMSAs for which relative pollution intensities were calculated, as shown in Table 2.
- Class 2: The 31 counties included in the last 13 SMSAs listed under "Hydrocarbons" in Table 2, i.e., Bridgeport to Fort Worth.
- Class 3: The 24 counties included in the SMSAs in Table 2 from Reading to Worcester, inclusive.
- Class 4: The 42 counties included in the SMSAs in Table 2 from Patterson-Clifton-Passaic to Richmond, inclusive.
- Class 5: The 52 counties in the SMSAs in Table 2 from Louisville to Gary-Hammond-East Chicago, inclusive.
- Class 6: The 37 counties in the first 12 SMSAs listed in Table 2, i.e., Los Angeles to New York, inclusive.

To classify the counties as to severity of sulfur dioxide pollution, it was necessary to consider the number and nature of the sulfur dioxide sources, i.e., the relative sulfur dioxide emissions in counties in the

65 SMSAs shown in Table 2, and the number of significant individual stationary sources present. This included the number of iron and steel mills, power plants with over 100 kw capacity, oil refineries with a capacity of over 20,000 barrels per day, and copper, lead and zinc smelters. Based on this information, the counties were placed in the following classes for sulfur dioxide pollution.

- Class 0: All counties with no significant sulfur dioxide sources. There were 2,798 such counties.
- Class 1: The 73 counties in the upper half of the SMSAs listed in Table 2 under sulfur dioxide.
- Class 2: 209 counties with 1-2 sources of sulfur dioxide.
- Class 3: 14 counties with 3-6 sources of sulfur dioxide.
- Class 4: 13 counties with 7 or more sources of sulfur dioxide.
- Class 5: 27 counties with copper, lead or zinc smelters.

The main sources of fluoride emissions known to adversely affect vegetation are ceramic plants, steel plants (especially in the Western United States), phosphorus and phosphate plants, and aluminum reduction plants. On this basis, the counties were classed as follows for fluoride pollution.

- Class 0: 3,048 counties with no significant fluoride sources.
- Class 1: 38 counties with large ceramic plants or a phosphorus or phosphate plant.
- Class 2: 23 counties with 2 phosphorus or phosphate plants.
- Class 3: 25 counties with aluminum reduction plants or a steel plant if west of the Rocky Mountains.

With the establishment of various classes of pollutant intensity for the three main types of pollutants, the next step was to estimate the losses that would occur to the various crops growing in counties in the different pollution classes. Table 12 shows estimates of the percentage losses to various crops that are likely to occur under the severest of conditions for each pollutant, i.e., Class 6 for oxidants, Class 5 for sulfur dioxide, and Class 3 for fluorides. With this as a basis, estimates were then made of percentage losses to various crops that would occur in the different classes. These are shown in Table 13 for oxidants, Table 14 for sulfur dioxide, and Table 15 for fluorides.

Some of these classes and the percentages involved require a little discussion. Class 1 for oxidants, including counties in the smaller SMSAs, was established because the literature indicates that low concentrations of oxides of nitrogen may cause reduced growth and yield without visibly affecting the plant. Therefore, a small reduction in yield was estimated for these counties. Recent work by Thompson et al.¹⁴ indicates that ambient levels of NO₂ that occur in the Los Angeles basin are probably

Table 13

FACTORS TO BE APPLIED TO CROP AND ORNAMENTAL PLANTING VALUES
WHEN PLANTS WERE EXPOSED TO DIFFERENT SEVERITY CLASSES OF OXIDANTS

Vegetation Types	Class						
	0	1	2	3	4	5	6
Field Crops							
Alfalfa	0	.010	.020	.040	.060	.070	.100
Barley	0	.005	.010	.020	.030	.040	.050
Beans	0	.010	.020	.040	.060	.080	.100
Buckwheat	0	.005	.020	.040	.060	.080	.100
Clover	0	.005	.020	.040	.060	.080	.100
Corn	0	0	0	.005	.010	.015	.020
Cotton	0	0	0	0	0	.005	.010
Oats	0	.005	.010	.020	.030	.040	.050
Peanuts	0	.005	.010	.020	.030	.040	.050
Rye	0	.005	.010	.020	.030	.040	.050
Sorghum	0	0	0	.005	.010	.015	.020
Soybeans	0	.005	.010	.020	.030	.040	.050
Sugar beets	0	.010	.020	.040	.060	.080	.100
Sunflower	0	.005	.010	.020	.030	.040	.050
Tobacco (cigar wrap)	0	.010	.020	.040	.060	.080	.100
Wheat	0	.005	.010	.020	.030	.040	.050
Seed Crops							
Alfalfa	0	.010	.020	.040	.060	.080	.100
Clover	0	.010	.020	.040	.060	.080	.100
Mustard	0	.010	.020	.040	.060	.080	.100
Citrus							
Grapefruit	0	.010	.060	.120	.180	.240	.300
Lemons	0	.010	.060	.120	.180	.240	.300
Oranges	0	.010	.060	.120	.180	.240	.300
Fruits and Nuts							
Apples	0	.005	.010	.020	.030	.040	.050
Avocados	0	.005	.010	.020	.030	.040	.050
Cherries	0	.001	.020	.040	.060	.080	.100
Figs	0	.001	.020	.040	.060	.080	.100
Grapes	0	.010	.020	.160	.240	.320	.400

Table 13 (Concluded)

Vegetation Types	Class						
	0	1	2	3	4	5	6
Vegetables							
Asparagus	0	0	0	0	0	.005	.010
Beans (snap)	0	.010	.020	.040	.060	.080	.100
Beans (Lima)	0	.005	.010	.020	.030	.040	.050
Beets	0	.010	.020	.040	.060	.080	.100
Broccoli	0	.005	.010	.020	.030	.040	.050
Brussels sprouts	0	0	0	0	.005	.005	.010
Cabbage	0	.005	.010	.020	.030	.040	.050
Carrots	0	0	0	.005	.010	.015	.020
Cauliflower	0	0	.010	.020	.030	.040	.050
Celery	0	.010	.020	.040	.060	.080	.100
Corn (sweet)	0	0	0	.005	.010	.015	.020
Cucumber	0	.005	.010	.020	.030	.040	.050
Endive	0	.010	.040	.080	.120	.160	.200
Lettuce (leaf)	0	.010	.020	.040	.060	.080	.100
Lettuce (head)	0	0	0	.005	.010	.015	.020
Muskmelon	0	.005	.010	.020	.031	.040	.050
Onion	0	0	0	.005	.010	.015	.020
Parsley	0	.005	.010	.020	.030	.040	.050
Potatoes (Irish)	0	.010	.020	.040	.060	.080	.100
Potatoes (sweet)	0	.005	.010	.020	.030	.040	.050
Pumpkin	0	.005	.010	.020	.030	.040	.050
Radish	0	.005	.010	.020	.030	.040	.050
Romaine	0	.010	.020	.040	.060	.080	.100
Spinach	0	.010	.020	.040	.060	.080	.100
Swiss chard	0	.005	.010	.020	.030	.040	.050
Tomatoes	0	0	0	.005	.010	.015	.020
Turnips	0	.005	.010	.020	.030	.040	.050
Nursery Crop	0	.005	.010	.020	.030	.040	.050
Floral Crops	0	.010	.020	.040	.060	.080	.100
Forests	0	.005	.010	.020	.030	.040	.050
Christmas trees	0	.010	.010	.040	.060	.080	.100
Parks	0	.003	.020	.040	.060	.080	.100
Highway plantings	0	.003	.020	.040	.060	.080	.100
Urban uses	0	.003	.020	.040	.060	.080	.100
Residential plantings	0	.003	.020	.040	.060	.080	.100

Table 14

FACTORS TO BE APPLIED TO PRODUCTION VALUES OF INDICATED CROPS
TO ESTIMATE LOSSES DUE TO SULFUR DIOXIDE
IN DIFFERENT CLASSES OF POLLUTION POTENTIAL

Vegetation Types	Class					
	0	1	2	3	4	5
Field Crops						
Alfalfa	0	.001	.001	.005	.020	.100
Barley	0	0	0	.002	.010	.050
Beans	0	0	0	.002	.010	.050
Buckwheat	0	.001	.001	.005	.020	.100
Clover	0	.001	.001	.005	.020	.100
Cotton	0	0	0	.001	.005	.050
Oats	0	0	0	.002	.010	.050
Rye	0	0	0	.002	.010	.050
Safflower	0	0	0	.002	.010	.050
Soybeans	0	0	0	0	.005	.020
Sugar beets	0	0	0	.002	.010	.050
Sunflower	0	0	0	.002	.010	.050
Wheat	0	0	0	.002	.010	.050
Seed Crops						
Alfalfa	0	.001	.001	.005	.020	.100
Clover	0	.001	.001	.005	.020	.100
Mustard	0	0	0	.002	.010	.050
Citrus						
Grapefruit	0	0	0	0	0	.010
Lemons	0	0	0	0	0	.010
Oranges	0	0	0	0	0	.010
Fruits and Nuts						
Almonds	0	0	0	.002	.010	.050
Apricots	0	0	0	0	.005	.020
Cherries	0	0	0	0	.003	.010
Grapes	0	0	0	0	.005	.020
Peaches	0	0	0	0	.005	.020
Pears	0	0	0	.002	.010	.050
Plums	0	0	0	0	.005	.020
Walnuts	0	0	0	0	.003	.010

Table 14 (Concluded)

Vegetation Types	Class					
	0	1	2	3	4	5
Vegetables	0	0	0	0	.003	.010
Asparagus	0	0	0	.002	.010	.050
Beans (snap)	0	0	0	.002	.010	.050
Beans (Lima)	0	0	0	.002	.010	.050
Beets	0	0	0	.002	.010	.050
Broccoli	0	0	0	.002	.010	.050
Brussels sprouts	0	0	0	.002	.010	.050
Cabbage	0	0	0	0	.003	.010
Carrots	0	0	0	.002	.010	.050
Cauliflower	0	0	0	0	.005	.020
Celery	0	0	0	0	.003	.010
Corn (sweet)	0	0	0	0	.003	.010
Cucumber	0	0	0	0	.005	-
Endive	0	0	0	.002	.010	.050
Eggplant	0	0	0	0	.005	.020
Lettuce (head)	0	0	0	0	.005	.020
Muskmelon	0	0	0	0	.003	.010
Okra	0	0	0	.002	.010	.050
Onion	0	0	0	0	.005	.020
Parsley	0	0	0	0	.005	.020
Parsnip	0	0	0	0	.005	.020
Peas	0	0	0	0	.005	.020
Peppers	0	0	0	0	.005	.020
Potatoes (sweet)	0	0	0	.002	.010	.050
Pumpkin	0	0	0	.002	.010	.050
Radish	0	0	0	0	.005	.020
Romaine	0	0	0	0	.003	.010
Spinach	0	0	0	0	.003	.010
Squash	0	0	0	.002	.010	.050
Swiss chard	0	0	0	.002	.010	.050
Tomatoes	0	0	0	0	.005	.020
Turnips	0	0	0	.002	.010	.050
Forest products	0	.001	.001	.002	.005	.010
Parks	0	0	0	.002	.020	.100
Highway plantings	0	0	0	.002	.020	.100
Urban uses	0	0	0	.002	.020	.100
Residential plantings	0	0	0	.002	.020	.100

Table 15

FACTORS TO BE APPLIED TO PRODUCTION VALUES OF VARIOUS CROPS
TO OBTAIN ESTIMATES OF LOSSES DUE TO FLUORIDES
UNDER DIFFERENT CLASSES OF FUMIGATION

Vegetation Types	Class			
	0	1	2	3
Field Crops				
Alfalfa	0	.002	.020	.100
Clover	0	.002	.020	.100
Corn (field) silage	0	.002	.020	.100
Lespedeza	0	.002	.020	.100
Grass Hay	0	.002	.020	.100
Pasture	0	.00002	.0003	.001
Citrus				
Grapefruit	0	0	.001	.005
Lemons	0	0	.001	.005
Oranges	0	0	.001	.005
Fruits and Nuts				
Apricots	0	.002	.020	.100
Blueberries	0	0	.010	.050
Cherries	0	0	0	.010
Grapes	0	0	.010	.050
Peaches	0	0	0	.030
Pears	0	0	0	.010
Pecans	0	0	0	.010
Plums	0	0	.010	.050
Prunes	0	0	.010	.050
Raspberries	0	0	0	.020
Strawberries	0	0	0	.020
Walnuts	0	0	0	.020
Vegetables				
Asparagus	0	0	0	.010
Beans (snap)	0	0	0	.010
Beans (Lima)	0	0	0	.010
Beets	0	0	0	.010
Celery	0	0	0	.010
Corn (sweet)	0	0	.010	.050
Lettuce (head)	0	0	0	.010
Forest products	0	0	.010	.050
Nursery crop	0	0	.010	.050
Floral crop	0	0	0	.010
Parks	0	0	.004	.025
Highway plantings	0	0	.002	.010
Urban uses	0	0	.002	.020
Residential plantings	0	0	.010	.050

without effect on citrus. Since the concentrations of NO_2 in the Los Angeles basin are much greater than in the counties in Class 1, losses ascribed in Class 1 may not be warranted. However, more studies are needed before this class can be eliminated.

There is room for argument about the oxidant pollution classes in which the SMSAs were placed, especially the first 12 in Table 2 (Class 6). Thus, the range of pollution potential is from 41 to 648, but placing them in the same class implies that plant damage is equal in all of them. It may have been better to have placed Los Angeles-Long Beach in one class, San Francisco-Oakland in a second class, San Diego and San Jose in a third, Chicago in a fourth, and the remainder of those now in Class 6 into another class--in other words, split the present Class 6 into five classes. However, this would have resulted in extremely complicated calculations. The ranges of relative pollution potentials in the remainder of the classes were not so great and seemed reasonable. The effect of the present groupings has no doubt been to raise the dollar loss estimate somewhat.

Many plant responses are logarithmic in nature. If logarithmic values are assigned to the relative pollution potential for hydrocarbons shown in Table 2, the relative levels--in terms of their effect on vegetation--are:

Class	Relative Potential Range	
	As Calculated	Log_{10} as Calculated
6	41-648	1.65 - 2.81
5	20-38	1.30 - 1.58
4	12-19	1.08 - 1.27
3	7-11	0.84 - 1.04
2	1-6	0.03 - 0.78

On the logarithm basis, the division into the five classes does not appear too inappropriate. However, even the logarithmic values for Los Angeles and San Francisco are high compared to the others; in future estimates, these two SMSAs may be put in a class by themselves.

Class 1 for sulfur dioxide includes about a third of the SMSAs--those with the greatest potential for SO_2 pollution. Although Los Angeles County ranks eighth in this group, very little injury to vegetation due to SO_2 is reported in Los Angeles County these days and there may not be significant dollar loss. In fact, in 1970 only two reports of plant damage to crops by SO_2 were recorded (both to azaleas), and there were no reports of damage to alfalfa, which is more sensitive than azaleas.¹² Thus this class may result in some overestimate of losses due to sulfur dioxide. However, the potential is there and the class has been included.

As stated previously, to obtain a reasonable estimate of dollar loss due to a pollutant, it is necessary to know the value of a crop or vegetation

type under polluted conditions and the percentage of reduction in yield caused by the pollutant. The data obtained in 1970 on commercial crops and those presented in previous sections on grass hays, forests, and ornamentals provide the necessary information on the dollar value of the vegetation types. The data presented in Tables 13, 14, and 15 give the percentage loss that would be expected to occur to each crop or vegetation type under different degrees of pollution. To derive estimates of crop loss, when data by county were available (i.e., on commercial crops), the percentage loss factors were applied to each crop in each county for each pollutant, and the county values were added to provide state totals.

Where only state values were available (i.e., for forests and ornamental plants), the loss factors for the counties involved were averaged, and this value was applied to the value of the vegetation type to give an average state loss value for each type.

Dollar Loss

The estimates of losses in each county were assessed based on crop values and estimates of pollution potential for the counties totaled into state values. Table 16 shows the totaled values for Pennsylvania and is included to indicate the general detail of the information that was assembled. However, because in many instances only one significant source was present in an area and to preserve some anonymity, the data were integrated into crop types and standard geographical regions of the United States (described on page 23).

The value of the crops grown in the counties where plant-damaging pollution was likely to occur and the estimated dollar losses to the main types of crops ascribable to the different pollutants are shown in Table 17 for the different regions. The last section of the table sums the values for the different regions into the values for the entire country.

The estimate of losses to crops totals about \$85.5 million, of which \$78 million is due to oxidants, the remainder (\$7.5 million) to sulfur dioxide and fluorides.

The losses estimated for citrus are greater than for any other type of crop, accounting for 33% of the total crop loss estimates. This is, of course, related to the fact that the production of citrus occurs in the most severely polluted areas. Field crops rank second to citrus, accounting for 28% of the crop losses. This is partly related to the importance of alfalfa as a field crop and its sensitivity to all the pollutants being considered.

Ornamental loss estimates as shown here include several types of plantings, as indicated in Tables 6 through 10. The total loss for this category is about \$46.5 million, of which \$43.5 million is due to oxidants, \$3 million to sulfur dioxide, and \$127 thousand to fluorides.

Table 16

ESTIMATED PLANT VALUES AND LOSSES FROM AIR POLLUTION
IN PENNSYLVANIA

Plant	Value in Polluted Counties (\$000)	Losses (\$000) Due To			
		Oxidants	Sulfur Dioxide	Fluorides	Total
Field Crops					
Alfalfa hay	\$ 37,312.4	\$ 343.2	\$148.3	\$0.0	\$ 491.5
Barley	4,194.8	15.4	4.5	.0	19.9
Buckwheat	105.6	1.3	0.0	.0	1.3
Clover hay	17,775.4	118.8	76.4	.0	195.2
Corn for grain	44,384.1	19.5	0.0	.0	19.5
Corn for silage	19,670.0	3.4	0.0	.0	3.4
Grass hay	417.3	0.0	0.0	.0	0.0
Oats	7,318.7	42.4	18.6	.0	61.0
Pasture	2,756.7	0.0	0.0	.0	0.0
Soybeans	569.6	1.0	0.2	.0	1.2
Tobacco	10,652.7	0.6	0.0	.0	0.6
Wheat	12,370.6	67.4	8.5	.0	75.9
Total	157,527.8	613.0	256.5	0.0	869.5
Seed Crops					
Red clover	145.2	5.1	0.3	0.0	5.4
Lespedeza	53.5	0.0	0.0	.0	0.0
Mustard	21.3	0.4	0.0	.0	0.4
Total	220.0	5.5	0.3	0.0	5.8
Citrus	0.0	0.0	0.0	0.0	0.0
Total	0.0	0.0	0.0	0.0	0.0
Fruits and Nuts					
Apples	4,259.6	162.9	0.0	0.0	162.9
Sour cherries	599.8	16.7	0.9	.0	17.6
Sweet cherries	347.3	11.1	0.5	.0	11.6
Grapes	4,742.9	98.4	0.1	.0	98.5
Peaches	2,891.5	388.1	0.3	.0	388.4
Plums and prunes	178.0	11.1	0.0	.0	11.1
Total	13,018.9	688.3	1.8	0.0	690.1

Table 16 (Concluded)

Plant	Value in Polluted Counties (\$000)	Losses (\$000) Due To			
		Oxidants	Sulfur Dioxide	Fluorides	Total
Vegetable Crops					
Snap beans	\$ 39.0	\$ 0.8	\$ 0.0	\$0.0	\$ 0.8
Table beets	3.2	0.4	0.0	.0	0.4
Broccoli	2.6	0.5	0.0	.0	0.5
Carrots	1.1	0.2	0.0	.0	0.2
Sweet corn	46.6	0.2	0.0	.0	0.2
Cucumbers	22.7	0.2	0.0	.0	0.2
Lettuce	5.0	0.0	0.0	.0	0.0
Sweet peppers	15.6	0.1	0.0	.0	0.1
Potatoes	16,296.7	687.6	0.0	.0	687.6
Sweet potatoes	26.3	1.7	0.0	.0	1.7
Spinach	1.7	0.0	0.0	.0	0.0
Squash	2.3	0.0	0.0	.0	0.0
Tomatoes	174.4	0.1	0.1	.0	0.2
Turnips	14.1	0.1	0.0	.0	0.1
Total	16,651.2	691.9	0.1	0.0	692.0
Nursery/Forest Crops					
Nursery products	9,074.0	256.0	6.7	0.0	264.7
Floral products	22,443.8	1,442.3	40.6	.0	1,482.9
Forest products	911.3	16.0	1.0	.0	17.0
Total	32,429.1	1,714.3	50.3	0.0	1,764.6
Crop Total	219,847.0	3,713.4	309.0	0.0	4,022.4
Ornamentals					
Forests	7,650.0	342.1	9.9	0.0	352.0
Highway plantings	1,088.0	9.4	0.7	.0	10.1
Parks	6,130.0	74.3	7.4	.0	81.7
Residences	59,415.0	2,080.5	175.1	.0	2,255.6
Urban uses	35,590.0	104.5	49.8	.0	154.3
Total	109,873.0	2,610.8	242.9	0.0	2,853.7
Total All Plants	\$329,720.0	\$6,324.2	\$551.9	\$0.0	\$6,876.1

Table 17

ESTIMATES OF ANNUAL VALUE OF CROPS AND ORNAMENTALS GROWN IN GEOGRAPHIC REGIONS
OF THE UNITED STATES AND ESTIMATED LOSSES DUE TO AIR POLLUTION

Region and Plant	Value in Polluted Areas (\$000)	Losses (\$000) Due To			
		Oxidants	Sulfur Dioxide	Fluorides	Total
New England					
Field crops	\$ 52,558.9	\$ 1,365.7	\$ 6.6	\$ 0.0	\$ 1,372.3
Seed crops	31.8	0.3	0.0	0.0	0.3
Fruit and nuts	8,904.3	482.8	0.2	0.0	483.0
Vegetables	10,496.9	510.2	0.0	0.0	510.2
Nursery and forest	33,673.9	1,246.2	0.1	0.0	1,246.3
Citrus	0.0	0.0	0.0	0.0	0.0
Crop Total	105,665.8	3,605.2	6.9	0.0	3,612.1
Ornamentals	168,332.0	1,941.5	0.0	0.0	1,941.5
Total All Plants	273,997.8	5,546.7	6.9	0.0	5,553.6
Middle Atlantic					
Field crops	301,535.9	1,155.9	351.4	951.5	2,458.8
Seed crops	322.2	8.9	0.6	0.1	9.6
Fruits and nuts	60,234.8	4,747.4	8.8	0.0	4,756.2
Vegetables	36,628.7	1,278.2	2.3	0.1	1,280.6
Nursery and forest	82,137.7	4,379.7	54.8	15.1	4,449.6
Citrus	36.8	0.4	0.0	0.0	0.4
Crop Total	480,896.1	11,570.5	417.9	966.8	12,955.2
Ornamentals	243,141.7	4,392.9	335.1	0.0	4,728.0
Total All Plants	724,037.8	15,963.4	753.0	966.8	17,683.2
East North Central					
Field crops	980,263.0	5,925.8	270.5	187.1	6,383.4
Seed crops	1,769.0	52.4	1.4	1.8	55.6
Fruits and nuts	17,018.0	550.8	1.5	0.9	553.2
Vegetables	19,244.1	682.3	2.5	0.0	684.8
Nursery and forest	73,072.1	3,675.5	0.9	10.0	3,686.4
Citrus	0.0	0.0	0.0	0.0	0.0
Crop Total	1,091,366.2	10,886.8	276.8	199.8	11,363.4
Ornamentals	272,385.0	13,854.1	1,593.7	0.0	15,447.8
Total All Plants	1,363,751.2	24,740.9	1,870.5	199.8	26,811.2
West North Central					
Field crops	362,290.3	1,112.6	26.4	7.7	1,146.7
Seed crops	1,083.4	18.3	0.1	0.0	18.4
Fruits and nuts	1,245.1	66.9	0.0	0.0	66.9
Vegetables	4,099.1	294.4	0.0	0.0	294.4
Nursery and forest	16,574.0	614.6	0.2	0.0	614.8
Citrus	0.0	0.0	0.0	0.0	0.0
Crop Total	385,291.9	2,106.8	26.7	7.7	2,141.2
Ornamentals	66,943.0	1,393.5	0.0	0.0	1,393.5
Total All Plants	452,234.9	3,500.3	26.7	7.7	3,534.7

Table 17 (Continued)

Region and Plant	Value in Polluted Areas (\$000)	Losses (\$000) Due To			
		Oxidants	Sulfur Dioxide	Fluorides	Total
<u>South Atlantic</u>					
Field crops	\$ 257,623.5	\$ 3,240.9	\$ 49.9	\$ 93.0	\$ 3,383.8
Seed crops	480.3	0.8	0.0	0.0	0.8
Fruits and nuts	5,568.4	30.1	0.1	26.6	56.8
Vegetables	8,610.0	160.7	0.0	0.7	161.4
Nursery and forest	61,137.8	889.6	0.9	186.9	1,077.4
Citrus	164,867.9	5,655.9	0.0	338.0	5,993.9
Crop Total	498,287.9	9,978.0	50.9	645.2	10,674.1
Ornamentals	139,292.0	4,633.5	364.8	0.0	4,998.3
Total All Plants	637,579.9	14,611.5	415.7	645.2	15,672.4
<u>East South Central</u>					
Field crops	171,352.8	495.6	10.6	202.2	708.4
Seed crops	162.4	1.4	0.0	0.2	1.6
Fruits and nuts	3,106.0	79.6	0.0	0.4	80.0
Vegetables	8,599.2	108.6	0.0	0.0	108.6
Nursery and forest	12,714.3	323.6	10.9	8.9	343.4
Citrus	0.0	0.0	0.0	0.0	0.0
Crop Total	195,934.7	1,008.8	21.5	211.7	1,242.0
Ornamentals	74,036.0	1,568.7	48.1	0.0	1,616.8
Total All Plants	269,970.7	2,577.5	69.6	211.7	2,858.8
<u>West South Central</u>					
Field crops	445,197.9	1,077.6	874.2	52.1	2,003.9
Seed crops	275.2	3.0	0.6	16.0	19.6
Fruits and nuts	1,362.2	9.4	0.0	3.3	12.7
Vegetables	1,478.1	16.2	0.2	0.1	16.5
Nursery and forest	16,239.3	216.8	29.6	11.6	258.0
Citrus	1,231.1	12.5	0.0	0.0	12.5
Crop Total	465,783.8	1,335.5	904.6	83.1	2,323.2
Ornamentals	109,974.0	1,406.3	253.8	0.0	2,060.1
Total All Plants	575,757.8	3,141.8	1,158.4	83.1	4,383.3
<u>Mountain</u>					
Field crops	247,950.8	603.6	1,354.8	198.3	2,156.7
Seed crops	114.1	0.9	0.1	0.0	1.0
Fruits and nuts	2,504.1	43.7	5.1	0.0	48.8
Vegetables	9,123.5	134.2	0.2	0.0	134.4
Nursery and forest	17,453.8	505.7	14.7	5.3	525.7
Citrus	24,089.8	843.1	3.4	0.0	846.5
Crop Total	301,236.1	2,131.2	1,378.3	203.6	3,713.1
Ornamentals	48,259.0	485.3	231.8	76.9	794.0
Total All Plants	349,495.1	2,616.5	1,610.1	280.5	4,507.1

Table 17 (Concluded)

Region and Plant	Value in Polluted Areas (\$000)	Losses (\$000) Due To			
		Oxidants	Sulfur Dioxide	Fluorides	Total
<u>Pacific</u>					
Field crops	\$ 537,722.2	\$ 3,006.5	\$ 109.7	\$1,278.4	\$ 4,394.6
Seed crops	11,644.7	113.7	7.2	0.0	120.9
Fruits and nuts	234,048.6	4,530.3	1.0	233.3	4,764.6
Vegetables	71,366.8	155.9	0.0	1.0	156.9
Nursery and forest	112,409.4	6,642.3	22.2	327.9	6,992.4
Citrus	157,833.3	20,917.2	1.9	50.1	20,969.2
Crop Total	1,125,025.0	35,365.9	142.0	1,890.7	37,398.6
Ornamentals	223,744.0	13,331.3	151.9	50.0	13,533.2
Total All Plants	1,348,769.0	48,697.2	293.9	1,940.7	50,931.8
<u>Total United States</u>					
Field crops	3,357,000	17,984	3,044	2,970	24,008
Seed crops	16,000	200	10	18	228
Fruits and nuts	334,000	10,541	17	265	10,822
Vegetables	170,000	3,341	5	2	3,348
Forest and nursery	425,000	18,494	134	566	19,194
Citrus	348,000	27,429	5	388	27,823
Crop Total	4,650,000	77,989	3,225	4,209	85,423
Ornamentals	1,346,000	43,407	2,979	127	46,513
Total All Plants	\$5,996,000	\$121,396	\$6,204	\$4,336	\$131,936

The losses to ornamentals due to sulfur dioxide and fluorides are mostly for forest losses as contrasted to Christmas tree losses, which are included under forestry and nursery crops. The total loss estimate for crops and ornamentals is about \$132 million.

The area of greatest loss is associated with the industrialized and heavily populated areas. Thus, if citrus is ignored, about 56% of the crop loss and almost 50% of the ornamental losses occur in the New England, Middle Atlantic, and East North Central States. The loss to ornamentals in the Pacific region is almost entirely due to losses in the Los Angeles basin.

Another approach to evaluation of the data is to consider the estimated losses as a percentage of the value of the crops produced. This can be done in two ways: (a) as a percentage of the value in the polluted counties and (b) as a percentage of the total crop production in both polluted and unpolluted areas. Such percentages for total crops and total ornamentals are given in Table 18 for the various geographic regions. The percentages were obtained by simply dividing the loss estimate by the crop value in the respective areas. In reviewing the table, it is immediately apparent that estimated losses to ornamentals represent a higher proportion of the total value than do the estimated losses to crops.* This, of course, is because most of the ornamental plantings are in heavily populated counties close to sources of pollution, whereas crops are generally grown away from such sources. Furthermore, the percentage losses for ornamentals are not much higher in polluted areas than in the entire region, i.e., polluted plus nonpolluted areas. Again, this indicates that most of the ornamental plantings are in the polluted counties. The percentage losses to ornamentals when the entire region is considered are generally highest in the so-called agricultural or "bread-basket" regions of the country, i.e., the central and mountain regions. On the other hand, the crop loss percentages are low in these regions and higher on either coast. The percentages for crop loss in the East North Central, West North Central, East South Central, West South Central and Mountain regions average 0.21 percent of the total value of crops produced. The overall crop loss in the United States is 0.46 percent. Higher percentage crop losses occur in the Pacific and South Atlantic States because most of the citrus is grown in those regions. The estimated loss of citrus in California represents about 13 percent of the value of the crop in the polluted counties, in Florida about 3.5 percent. This does not mean that Florida citrus is more resistant, but only that it is grown under less severe pollution conditions than in California.

*The New England and Middle Atlantic regions are exceptions.

Table 18

ESTIMATED PERCENTAGE OF CROP AND ORNAMENTAL VALUES LOST
IN POLLUTION-THREATENED COUNTIES AND IN THE
GEOGRAPHIC REGIONS AS A WHOLE

<u>Region and Vegetation Type</u>	<u>Percentage Value Lost</u>	
	<u>Polluted Counties</u>	<u>Entire Region</u>
New England		
Crops	3.41	1.10
Ornamentals	1.15	1.00
Middle Atlantic		
Crops	2.70	1.68
Ornamentals	1.85	1.32
East North Central		
Crops	1.04	0.42
Ornamentals	5.29	3.70
West North Central		
Crops	0.54	0.08
Ornamentals	2.09	1.36
South Atlantic		
Crops	2.15	0.31
Ornamentals	3.42	1.93
East South Central		
Crops	0.60	0.11
Ornamentals	2.16	1.70
West South Central		
Crops	0.49	0.10
Ornamentals	1.73	1.40
Mountain		
Crops	1.22	0.37
Ornamentals	1.24	0.68
Pacific		
Crops	3.32	1.13
Ornamentals	5.99	4.37
United States		
Crops	1.84	0.46
Ornamentals	3.29	2.37

IV DISCUSSION

The values for economic losses of plants due to air pollutants are based on fuel consumption data for 1963 and agricultural crop value data for 1964, the most recent years for which the complete or detailed data needed were available. However, a method of evaluating these data has been developed and can be applied to new data on pollution and vegetation values on a county-by-county basis as they become available.

The method itself requires some additional discussion, although some details have been considered in the section describing the methods. The value estimates are for the counties in which the source is located. In many instances, because of wind direction and topography, it is possible for a source to be in one county and affect vegetation in the next county. This possibility is, of course, recognized. It was believed that when this occurred, the values calculated would be more or less equalized since the source county would actually suffer no loss but a loss would be shown, while no loss would be shown for the adjacent county. The agriculture and types of plantings are not likely to change greatly across county lines. There are some exceptions, of course, a few of which have been considered here, but these exceptions may also tend to equalize each other. This difficulty is greater with single large sources than with the general urban sources since the SMSAs include several counties around large metropolitan areas. The Chicago SMSA, for example, includes five counties whose total area is about the same as that of Los Angeles County (some 4,000 square miles), and there are areas in Los Angeles County relatively free of air pollutants.

With establishment of the relative pollution level in various counties, it was then necessary to estimate the percentage of loss that would occur to crops and ornamentals as a result of the various pollutants in each county. The procedures followed in arriving at these loss factors were briefly described under Methods, but a more detailed discussion seems warranted. There have been many publications dealing with effects of air pollutants on vegetation, as indicated by various review articles: Jacobson and Hill,¹⁵ Heggstad,¹⁶ Brandt and Heck,¹⁷ Thomas,¹⁸ Weinstein,¹⁹ Taylor,²⁰. A relatively few of these have dealt with actual yield losses. Most of them have been concerned with markings produced on leaves or with effects on dry weights and other growth indicators during relatively long or short growth periods. For this reason, rather heavy reliance has been placed on the few published and, in some cases, private communications that give data on yields.

In estimating yield losses under various conditions, each pollutant has its own special considerations. Oxidants kill portions of the leaves; where this occurs, quantitative estimates of reduction in photosynthetic area may be extrapolated to indicate yield loss. Oxidants may also produce a general reduction in growth and yield that would not be apparent

unless comparisons with nearby unfumigated plants were possible. Furthermore, although reduction in growth may be a disadvantage or loss to a commercial crop, it may be a gain in an ornamental planting because less maintenance is required, i.e., pruning or mowing.

Sulfur dioxide affects vegetation through killing of leaf tissue, with a resultant reduction in photosynthetic area. The growth and yield of vegetation does not appear to be affected by sulfur dioxide unless leaf tissue is killed.¹⁸

Fluorides affect vegetation by marking the leaves. In some instances, crop and ornamental losses have resulted from such markings. However, on the whole, the greatest economic loss to vegetation as a result of fluoride is the rendering of forage crops unfit for animal consumption.¹⁹

The loss factors ascribed to oxidants were based primarily on the percentage loss estimates that were made for Los Angeles County during 1967, 1968, and 1970 by the California State Department of Agriculture.^{9, 10, 12} These were on-the-scene estimates by individuals trained in effects of air pollutants. These percentages of loss estimates cover a wide range of crops, including fruits and vegetables, field crops, cut flowers, and nursery crops. They include more crops than for any other area. Since Los Angeles Basin counties have the severest oxidant pollution potential, loss factors in other areas were assigned based on their pollution class relative to that in the Los Angeles area.

However, there are additional studies and reports on the effects of oxidants on plants, and these were also considered in arriving at loss factors. The studies by LaCasse¹³ during the last two years are as comprehensive for Pennsylvania as the ones for California; thus, the results reported for Pennsylvania influenced the assigning of loss factors since a different area of the country is involved. Other studies considered included the following: Thompson and Taylor²¹ on citrus; Thompson²² on grapes; Heggstad²³ on potatoes in Maryland; Heck²⁴ on soybeans in North Carolina; Feder and Campbell²⁵ on carnations in Massachusetts; Miller²⁶ on forest trees in California; Dochinger²⁷ on forest trees in Ohio.

Class No. 1 for oxidant effects was established to include "hidden injury" effects due to these pollutants. Based on the results obtained by Taylor and Eaton,²⁸ it was believed that nitrogen dioxide was important in this connection. Recent studies, including those by Thompson et al.,¹⁴ indicate that no such effects are occurring to citrus in Los Angeles County. Since Los Angeles County is one of the heaviest NO₂-polluted counties, the postulated effects of NO₂ may have to be revised.

The estimated loss factors due to sulfur dioxide were based primarily on publications of Thomas¹⁸ and Brisley and coworkers.^{29, 30} They actually

studied yields of crops under various field fumigation conditions in the vicinity of smelters where heaviest losses due to SO_2 occur, and developed formulae for calculating yield reduction. The above work was carried out in the western United States. Of equal importance is the work by Dreisinger³¹ and Linzon³² in eastern Canada. The results reported by these investigators, plus the data on relative sensitivity, have provided the basis for estimating vegetation losses due to sulfur dioxide.

There have been very few studies on the effects of fluorides on yield. The scarcity of such information is brought out by Weinstein.¹⁹ Some studies that were utilized in arriving at loss factors due to fluorides are as follows: Brewer et al.³³ and Thompson et al.²¹ on citrus; Adams et al.³⁴ on Ponderosa pine; Hitchcock et al.^{35,36} on sorghum and gladiolus.

As indicated above, the greatest economic impact of fluorides on vegetation is the rendering of forage crops unusable as a result of fluoride accumulation, even though the growth of the plant is not affected. Loss factors due to this cause have been mostly derived from unpublished reports of fluoride content of forage crops in the vicinity of aluminum, steel, and phosphorus or phosphate plants, to which we had access.

It will be noticed that there are many blank spaces in the table indicating sensitivity of species to various air pollutants. Information on these species is not available. It may develop that some of these are very sensitive to certain pollutants and, although in this report no loss has been said to occur to them, later research may show that loss is indeed occurring. However, most of the major crops have been investigated or at least closely observed, and it does not seem likely that large increases in dollar loss will later be assessed because of sensitivities not now known. Also, it is possible that some of the indicated dollar losses may be too large. In this report, factors for loss to grapes and citrus ascribable to oxidants have been based on experiments in which plants were grown essentially under greenhouse conditions (the only method presently available), and these growth conditions may have increased their sensitivity; thus, the losses may not be as high under actual field conditions.

Systematic application of factors to crop and ornamental plant values, based on pollution conditions, is a straightforward procedure for estimating crop losses and eliminating hunches, etc., but it does prevent the consideration of interfering factors or special cases. The weather fleck on tobacco in the Connecticut Valley is a case in point. Higher losses occur there than would be expected based on pollution levels and tobacco sensitivity because of the special nature and requirement of the cured crop. In this instance, since the authors were aware of this and actually visited the area, special allowances were made. On the other hand, climatic conditions before and after a severe pollution episode may cause the plant damage to be much less or greater than

would be expected. Thus, the episode of heavy pollution that occurred in New Jersey, New York and Pennsylvania at the end of July in 1970 had surprisingly little effect on sensitive species.

In evaluating ornamental plantings, no attempt has been made to assign esthetic values. Instead, emphasis has been placed on the cost of establishment and maintenance. This does not mean that esthetic values are not real, but only that no satisfactory method is available for ascribing dollar values to them.

In some instances in years past, air pollutants have completely denuded certain areas or rendered productive land nonproductive. In other instances, air pollutants have made it impossible to grow certain crops in a particular area. In some cases, air pollutants have reduced or even eliminated the value of recreation areas through the killing of vegetation. Such losses in land value have not been included.

Because of the various sources of error and other factors mentioned above, it should be emphasized that the loss values presented in this report are estimates and, as such, are subject to error and open to revision. In fact, it is expected that suggested revisions will be forthcoming from many sources.

However, it is also believed that the loss estimates derived are reasonable and are not too far from the true values. There are several reasons for believing this.

Each year, the U.S. Department of Agriculture provides estimates of the losses to crops due to plant diseases, insects, weeds, and other pests. At the start of this study, individuals responsible for such estimates were consulted in the hope that we could obtain help in developing quick and accurate methods for estimating crop losses due to air pollutants. Their experience has been that reliable estimates can be obtained only by detailed on-the-spot observation on almost a field-by-field basis. Two states, California and Pennsylvania, have been conducting such surveys, and it is interesting to compare the estimates derived in this report with those obtained by these two states. The values given below are for commercial crops only.

California:

Los Angeles County		SRI
1967	\$ 4,048,000 ⁹	
1968	2,536,000 ¹⁰	\$ 6,500,000
1970	2,855,000 ¹²	
Entire State		
1969	\$44,500,000 ¹¹	
1970	25,691,000 ¹²	\$35,230,000
Pennsylvania ¹³ :		
1969-1970	\$ 6,000,000	
1970-1971	437,200	\$ 7,391,000

(Pennsylvania, in considering losses, estimated only the cost of production and not what the grower might receive; therefore, the Pennsylvania estimates were doubled to arrive at the values given above and to make them comparable with the others.)

One possible reason for SRI estimates being so much higher than those of Pennsylvania is that where oxidants are the pollutants, the SRI loss factors include what might be called "hidden injury damage." Thus, in the Los Angeles area, any number of studies on many crops have shown reduced yields and growth without obvious symptoms developing on the vegetation. For the purpose of this report, such losses have been judged to occur throughout the United States. This may or may not be true, and only additional research can provide the answer. Inclusion of this "hidden injury" loss may mean that the SRI estimates of losses due to oxidants are higher than the actual losses.

The above data for California and Pennsylvania show how crop losses due to air pollutants can vary from year to year--depending on climatic, edaphic, and biotic factors. Other factors are also involved. The SRI values are based on 1963 crop production and values. In Los Angeles County, a great many citrus orchards were converted to housing developments between 1963 and 1967. Thus, the higher SRI values for Los Angeles County could reflect this shift in land use.

It is also of interest to compare individual crop loss estimates in California as compiled the State of California^{11, 12} and by SRI.

	California		SRI
	1969	1970	1963
Field crops	\$ 1,579,000	\$ 2,653,000	\$ 3,189,000
Citrus	33,565,000	19,553,000	20,969,000
Fruits and nuts	1,165,000	720,000	4,695,000
Vegetables	1,651,000	264,000	111,000

There are some differences in the estimates. For instance, SRI estimates of fruits and nuts losses are much greater than California's. This is related primarily to the values of the crops and the area included. In 1963, the value of the grape crop in Los Angeles, Riverside, San Bernardino, and Ventura Counties was about \$10,000,000. Applying the loss factor of 0.4 (California used 0.5), a loss value of \$4,000,000 is obtained. Of course, in SRI estimates, the value of the crop in the whole county is considered as being affected. In 1970, the value of grapes being affected in these counties was about \$1,600,000. SRI's estimate of vegetable losses was much less than California's. This seems to be related to the base value being considered. The State of California gives the harvest value of vegetable crops in 1970 as \$37,171,000. The harvest value on which SRI estimates are based was \$5,000,000.

Thus, on the basis of detailed estimates in California and Pennsylvania, two states greatly different in climate and agriculture, the loss estimates presented in this report are in general agreement with those obtained by detailed surveys, which are as accurate as can be derived.

To obtain a quick estimate of crop losses, an assumption was made that all of the crops in counties threatened with oxidant pollution were injured as much as in Los Angeles County. Such a procedure gave a loss value of about \$130 million. This was obviously too high, and the estimate of \$78 million derived in this report would appear to be reasonable.

In an early effort to arrive at an estimate of losses to ornamental plantings, it was assumed that all the nursery business conducted in counties threatened by oxidant pollution consisted of replacements of plants lost due to air pollution. Such an assumption gave a loss value of about \$150 million. The estimated loss to ornamentals of about \$43.5 million (due to oxidants) also appears reasonable since it is less than one-third of the total nursery business.

For all of the above reasons, it is believed that the crop and ornamental loss estimates ascribed to ozone, PAN, and oxides of nitrogen are close to the actual losses that would occur in an average year, particularly since the pollution intensities were calculated.

Comparison data for estimates of loss due to sulfur dioxide and hydrogen fluoride are not readily available. Pennsylvania indicated a loss of \$14,000 due to sulfur dioxide and none due to fluorides; the SRI estimates for Pennsylvania in this report are \$552,000 and none, respectively. Although the State of California report indicated that visible injury ascribable to these two pollutants was observed, the amount of crop loss was not given. The SRI procedure for estimating results in loss values of \$90,000 for sulfur dioxide and \$732,000 for fluorides in California. These values are largely the potential loss to alfalfa near large sulfur dioxide sources and potential loss of forage crops as a result of fluoride accumulation, rendering them unfit for feed. On the

basis of general experience, I believe that these estimates are not too far off. They could be low by as much as 100% in any one year. Most of the crop and ornamental losses occur in the vicinity of large single sources, and adverse weather conditions can result in severe plant-damaging fumigations. Thus, each fumigation source might be considered a special case. To properly evaluate loss to crops and ornamentals in the vicinity of these sources requires on-the-scene evaluations over a period of years. In a subjective approach, the author has had such experience with large emitters of sulfur dioxide and fluoride for many years, and these estimates are based on that experience. As indicated above, where direct comparisons are available, the estimates presented here are somewhat higher than those from other sources.

Considering the way in which sulfur dioxide sources are being concentrated in local areas and the erection of tall stacks as a compensating factor, I can envision a case in which a single sulfur dioxide incident might cause more damage than the \$6.2 million loss estimate given in this report.

This again emphasizes the fact that the estimates presented here are for an average year over the United States.

Earlier, it was pointed out that the total crop loss ascribable to air pollutants amounted to 0.46 percent of the total value of all crops produced in the United States. It is interesting to compare this loss estimate with those ascribable to other crop pests such as plant diseases, weeds, and insects. Data taken from Loss in Agriculture, U.S. Department of Agriculture Handbook #291, 1965, indicate that the average annual loss to crops due to plant diseases is \$3,068 million, to insects is \$2,965 million, and to weeds is \$1,828 million. These figures represent about 12, 12, and 8 percent, respectively, of the value of the total potential production. The Handbook gives \$325 million as the annual crop loss due to air pollutants, which would represent about 1.2 percent of the total crop value and is almost four times the dollar loss estimated in this report. In any event, the above data indicate that as a crop pest, air pollution is at present nowhere near the economic threat that weeds, insects, and diseases are.

However, there are certain factors that contribute in part to this difference. By the nature of man's activities, pollution-emitting sources and crop production activities almost cannot occur in the same location and both be economical, for reasons other than pollution. Furthermore, pollution sources cannot fly around the country at their whim as insects might, nor be carried as far by air currents and retain their plant-damaging potential as spores and seeds can. But in the few instances where crop production and heavy pollution do occur in the same general vicinity, there can be very high crop losses. Thus, grape yields are reduced by 40-50% in Los Angeles County, citrus by 20%, etc. In areas close to a single sulfur dioxide source, one fumigation episode may result in a loss of 50-60% to one cutting of alfalfa.

One objective of these investigations was to arrive at some evaluation of the crop loss that might be ascribed to automobile emissions. Since automobiles emit no fluorides, they cannot be held responsible for fluoride losses. Sulfur dioxide emissions from automobiles average less than 1% of the total emissions from all sources, and there may be some doubt as to whether auto exhaust emissions of sulfur dioxide would ever, by themselves, result in crop or vegetation losses. The data calculated here indicate that autos emit 67% to 85% of the hydrocarbons and 38% of the oxides of nitrogen into the atmosphere. If these values are applied directly to the estimated loss values given in this report, crop losses from automobiles could amount to about \$60 million on a hydrocarbon basis, or \$30 million on an oxides-of-nitrogen basis. Which of these two emissions is the limiting factor in the formation of ozone and PAN is not known. However, Schuck et al.³⁷ have shown a correlation between the hydrocarbon content of the atmosphere in the early morning (5-9 a.m.) and the maximum oxidant content later in the day (0.3 ppm of nonmethane hydrocarbon produces a maximum hourly concentration of oxidants of up to 0.1 ppm).

As indicated earlier, these values are estimates and, as such, subject to revision. There will be many exceptions taken to the estimates presented. The authors expect that where the effects of air pollutants are evaluated through state surveys, such as those conducted by California and Pennsylvania, recently initiated by New Jersey, and proposed by other states, revisions of loss estimates will occur.

It is my general feeling that losses ascribed to oxidants may be too high and those to the other pollutants a little low, but we have no way of substantiating these feelings at this time.

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